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Optimization of Binder Content in Paints to Partially Substitute Acrylate Content

Investigation of Binder Properties Through a Functional and Environmental Perspective

Master's thesis in Materials Chemistry

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Image of weathering test of paint coatings on planed and fine sawn boards.

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Abstract

The acrylate binder in the *Surface Protection* paint produced by *Sioo Wood Protection*, is suspected to be less environmentally friendly than the other binders in the paint. Therefore, a substitution of the binder with a more environmentally friendly alternative is of interest to the company. However, simultaneously, the company wants to retain desirable paint properties. To investigate alternatives, six different binders (named, *B1-B6*), were analyzed. The binders contained either silane and polymeric siloxane or fully reacted siloxane. Further, the binders were tested in paint matrices containing solely one binder (named, *monobinder paints*) or in paint matrices with several binders (named, *polybinder paints*). For the polybinder paints, two different ratios of acrylate content were tested, either a ratio where the investigated binder partially replaced the acrylate content or completely replaced it. In order to compare the properties, reference monobinder- and polybinder paints with the acrylate binder, and without any of the investigated binders, were formulated.

To evaluate if the binders were suitable for the Surface Protection paint, the functional properties and the environmental impact of monobinder- and polybinder paints were investigated. Test methods to evaluate the functional properties were: measurements of viscosity, solid content, color and gloss, cross hatch testing, stability tests, texture of paint coating, weathering test and accelerated weathering test. The environmental impact of the binders was limited to the manufacture and transportation of the binder i.e. step A1 and A2 in a *Life Cycle Analysis* (LCA). Testing of monobinder paints showed best results for binder B2, B5 and B6, all containing fully reacted siloxanes. Hence, these binder were selected for the production of polybinder paints. Testing of the polybinder paints showed best results when the acrylate content was partially substituted by binder B2, and when the acrylate content was completely substituted by binder B6. Binder B5, on the other hand, gave poor results, both when partially or completely replacing the acrylate content. The environmental impact was generally the lowest for paints with binder B6. However, only if the binder was transported by ship. The overall results, from both a functional and environmental perspective, suggest that binder B6 is the most preferable choice to substitute the acrylate binder and to obtain desirable properties with low environmental impact.

Keywords: Acrylate, Binders, Exterior paints, LCA, Silane, Siloxane, Paint optimization.

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Anna Bergenbrink, Julia Billstein, Gothenburg, June 2022

Contents

1

Introduction

Paint has been used since ancient times and the first paints are dated as far back as 25 000 years ago [1]. These paints were used for decoration and consisted of materials such as milk, limestone, and iron oxide pigments. It is not until more recently, that paint has started to be used as surface protection [2]. The protective value of drying oils in varnishes began to arise in Europe during the thirteenth century. The varnishes contained a continuous phase of hemp seed, linseed or walnut oil with some kind of dissolved naturally occurring binder. The varnishes usually darkened with time [1]. Water based paints, on the other hand, were not as frequently used at the time. The water based paints became more frequent during the twentieth century, especially in the US. The waterborne paints had advantages to the oil-based paints, they were safer and more environmentally friendly. Mainly because the paints possessed low flammability and contained few or zero volatile organic compounds (VOCs) and hazardous air pollutants (HAP) emissions [3].

The water based paints were first developed with naturally occurring binders e.g. linseed oil, but in the middle of the twentieth century, waterborne paint were developed with synthetic binders instead. The synthetic binders enhanced the properties of the water based paints e.g. color consistency [2]. However, the synthetic binders are often petroleum-derived. Petroleum-derived binders are not a sustainable choice because the source is not renewable. Consequently, the price of the petroleum binders have increased. At the same time, due to globalization, the competition between coating industries have increased as well. Hence, during the last decade, there have been a huge interest in sustainable development of paint and in high performance coatings. As a consequence, binders containing silicon have grown to be a frequently used binder in high-performance industrial maintenance paints. The silicon binders provide great thermal and ultraviolet (UV) radiation resistance; and low VOC; contrary to oil-based paints. The silicon binder is often combined with an organic binder e.g. acrylate, to make up for the typical brittleness and inflexibility [2].

As previously mentioned, paints have several functions other than being decorative, the paint can for example be used for preservation of wood articles and are arguably important when the wood articles are used as building materials. The coating provides a protection against e.g. mold and insects. Previous studies has shown that it is efficient to treat wood with alkali metal silicates. This gives wood a similar structure to petrified wood, meaning that the wood is mineralized, usually with silica [4]. The mineralization makes the wood stable over long time periods. The conventional methods use sodium silicate to impregnate the wood. One disadvantage, is that the sodium silicate treatment is fairly easily washed away by water.

Sioo Wood Protection produces SiOO:X which is a silicon based paint system comprised of two products, *Wood Protection* followed by *Surface Protection*. The application of the products is performed in a specific order. Year one, the Wood Protection is applied in two layers, followed by a layer of Surface Protection. The following year, depending on usage area, another layer of Surface Protection is applied with the intent to prolong the durability of the wood and the coating. The products are for exterior usage and usually unpigmented but Sioo Wood Protection also produces pigmented board paints for exterior vertical walls, paints that will from now on be called *panel paints*. The Wood Protection contains potassium silicate, containing silica, which penetrates and hardens the wood. The Surface Protection contains different types of binders e.g. silicon binders, in the form of silanes and siloxanes, and gives further protection by protecting the Wood Protection which does not contain any binders. The silicon binders are present in combination with other binders e.g. an acrylate binder. The Surface Protection allows a sufficient amount of moisture to enter in order to ensure that the process of mineralization and hardening by the Wood Protection can happen. It is due to mineralization of the surface that makes it possible for silanes to be used in the paint. A cluster of discrete, amorphous silica particles is formed when the silica polymers, from the Wood Protection, grow in size, and agglomerate in the wood cells and around the fibers. The cluster strengthens the wood and give the surface a gray tint. Additionally, the silica cluster provides protection against algae and mold; sunshine and UV rays; rain; frost and snow; and some types of rot e.g. blight [5]. At present time, Sioo Wood Protection uses a combination of different types of binders in the paint, as previously mentioned, where the acrylate binder is one of them. Furthermore, the acrylate binder is suspected to be less environmentally friendly compared to the other binders and therefore, alternative types of binders could be of interest to investigate.

1.1 Aim

The aim of the project is to investigate binders which are of interest to Sioo Wood Protection, and create paints where the quantity of acrylate binder is lower compared to the paints produced by the company today. The purpose of this is to create a more environmentally friendly paint where the acrylate content is substituted with one of the binders investigated. Thus, the new binders have to be evaluated both from an environmental perspective and from a functional perspective. Another goal is to produce matt paints because one demand from Sioo Wood Protection is that the paints should be matt, with other words have low amount of gloss.

The intent is to execute the project in two parts. Firstly, different binders will be examined in monobinder paints with the goal to determine the individual properties of each binder. The binders are selected based on knowledge from the company and literature search. Secondly, polybinder paints will be created where the acrylate content is partially substituted with the binders investigated. The purpose of the last step is to examine the paint properties when the acrylate content has been partially substituted, and to evaluate the compatibility within the paint matrix. At the same time, an environmental assessment will be performed in order to evaluate the binders from an environmental perspective.

1.2 Outline of Project

In Figure 1.1, an overall scheme is shown of the working procedure. Firstly, the project will begin with a literature study. Available binders at the company will be investigated by researching information about properties, hazards, silicon compound and content. The literature study is done in order to decide which binders that are most suitable for the project. Further, a selection of six binders will be made and thereafter paints with solely one binder will be produced with the selected binders. The paints containing only one binder will be called *monobinder paints*. The properties of the manufactured paints will be analyzed in different tests. Further, an evaluation of the monobinder paints will be made and thereafter three binders will be chosen to proceed with in the project.

In next part of the project, paints with a combination of several binders, including the three selected, will be formulated. These paints will be referred to as *polybinder paint*. The properties of the polybinder paints will be analyzed in different tests. Simultaneously as the monobinder and polybinder paints are manufactured and tested, an environmental assessment will be done for all six initially selected binders for the monobinder paints. Lastly, the results from the polybinder testing and environmental assessment will be analyzed and evaluated.

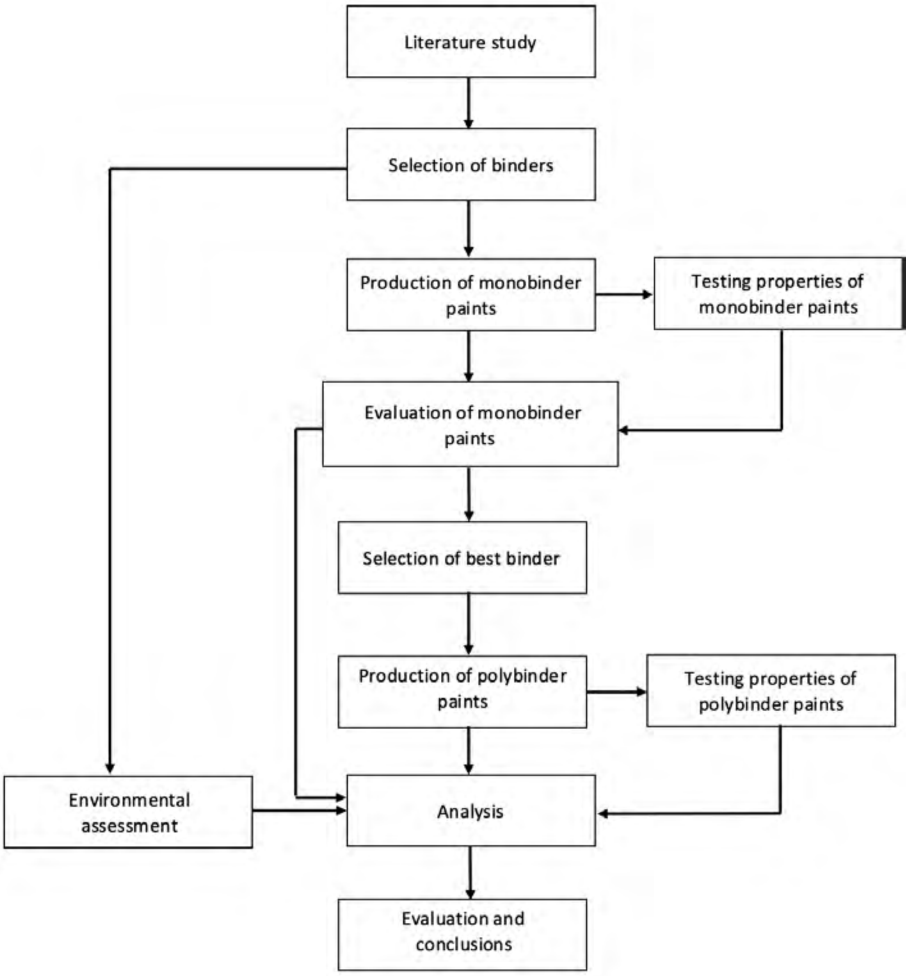


Figure 1.1: Scheme of the working procedure

A more detailed description of the method is included in the *Experimental procedure*, see Chapter 4.

1.3 Limitations

One limitation of the project is the number of binders and pigments that can be studied. The thesis is planned to be executed during a 20 week semester and this will limit the number of binders which can be tested, consequently a selection has to be made. Furthermore, the time limit will not allow long-term testing on the paints which would have been interesting in order to analyze long-term stability of the paints. The time limit will only allow predictions on long term stability. Additionally, other components of the paint, such as solvent and additives, will not be investigated. Lastly, due to time limit, a complete Life Cycle Analysis (LCA) will not be performed in the environmental assessment. Manufacture and transportation of the binders will be included. Moreover, packaging of binders was considered for the environmental assessment. However, since all binder are delivered in the same type of container, this is considered inapplicable and therefore excluded.

1.4 Specification of Issue Under Investigation

During the project the following questions will be examined:

- Which binders, of the ones investigated, have the best properties according to gloss, viscosity, durability, adhesion to substrate and color?
- Which binders are the best candidates to partially replace the acrylate currently used in paints at Sioo Wood Protection?
- What is the optimal degree to substitute the acrylate binder in polybinder paints in order to not degrade properties e.g. gloss, viscosity, durability, adhesion to substrate and color?
- Is it possible to produce a more environmentally friendly paint, evaluated by an environmental assessment, compared to the one produced today?

2

Theory

In the following section, an introduction to the concept of paint will be given. The introduction will include information about the components in paint that will be in focus for this project: binders and pigments. There will also be a short section about wood as a substrate, since all produced paints in the project will be applied on this material.

2.1 A Definition of Paint

The term *paint* can be defined as a liquid with color that is used to either protect and/or decorate a surface of an object [6]. The surface is often referred to as the *substrate*. A paint usually contains four main components; binder, pigment, solvent and additives. The binder is a crucial component because it is the main part of the coating upon drying, see Section 2.2. Next component, the pigment, adds color to the paint, see Section 2.3. The third component, the solvent, is used to disperse or dissolve the ingredients. This makes the term a bit deceptive as the solvent does not always dissolve the ingredients. Furthermore, the solvent is also used to make the coating process of the substrate possible and it decides the drying time of the paint. Lastly, the additives can facilitate application or increase stability of the paint, for example UV-stabilizers can be used to make the paint more UV resistant and defoamers can be used to prevent foaming of the paint [7].

2.2 Binders

Binders usually contain high molecular weight polymers. Their main function in paint is to create a film but also to allow bonding between pigments, and additionally between pigments and substrate. The main types of binders are oils, alkyds, acrylates, epoxies and polyurethanes. The binders can be categorized in to three classes; natural, modified and synthetic binders. Binders of natural origin are for example of linseed oil. Modified binders are natural binders which have been altered, for instance nitrocellulose or alkyd. Lastly, synthetic binders are e.g. acrylics, epoxies and polyurethanes. When the paint has been applied to the surface of an object, a drying process is occurring where the paint goes from liquid to dry state. The binder is present in both the wet and dry paint [8]. Architectural paints, in other words, paints that should be decorative or be used in households, are applied at ambient temperatures. Consequently, no extra heat or irradiation is used to cure the paint [9]. The drying process of architectural paints can be divided into two categories, *physical drying* and *chemical curing.* Chemical curing involves chemical crosslinking of low molecular weight polymers and the average molecular weight will increase with the number of crosslinkings. At some point, with increasing crosslinking, gelation will happen [10]. In fact, really high molecular weight products are produced [9]. Further, the crosslinking creates a three-dimensional polymer network in the solid paint and the network is irreversible [10, 11]. Consequently, water will not dissolve the network which means that the paint is washable once its dry [11]. Further, film properties can be improved by crosslinking [9]. Physical drying, on the other hand, involves high molecular weight polymers dispersed in a aqueous medium without crosslinking. For example, paints containing high molecular weight of acrylate polymer usually dries through physical drying and the drying time is usually short [12]. The physical drying then occurs when the solvent evaporates and coalescence of the amorphous, high molecular weight polymers, in other words latex particles, follows [9].

2.3 Pigments

A pigment is defined as a substance that gives color to an object when it is present or added to it [13]. Pigments contain organic or inorganic components. Inorganic pigments usually consist of a fine powder of minerals and are commonly more thermally stable compared to organic pigments. Organic pigments are generally low in molecular weight and are often brighter and more transparent than inorganic pigments [14]. It is of importance that the pigments are evenly distributed in the paint to get a homogeneous color. An even distribution can be achieved by the use of surface active components which act both as a wetting agent for the pigment and as a stabilizer [7].

When creating a paint an important parameter is the so-called *Pigment Volume Concentration* (PVC). This value is defined as the fractional volume of dry pigment in the total volume solids content in the dry paint film. The *volume solids* refers to the solid content of the paint, see Section 2.4. PVC can be formulated as follows,

$$PVC = \frac{V_\mathrm{p}}{V_\mathrm{p} + V_\mathrm{b}} \tag{2.1}$$

where V_p is the volume of pigment and V_b is the dry volume of binder. This value gives an indication of the properties of the paint and is a useful aid when creating a paint. On the other hand, calculated PVC is only a predicted model, the actual value of PVC can differ when making a paint in practice. The PVC can, for example, differ if the binder shrinks during the drying or curing process. Additionally, the formula for PVC does not include some additives that do not go under the category binder or pigment, but still these additives can influence the actual PVC [15]. Furthermore, pigments can differ in size and have different particle size distribution (PSD). PSD will also impact the real PVC because it affects the packing of pigments, for example small particles can fill interstices between larger particles [16].

Critical Pigment Volume Concentration (CPVC) can be used to determine a workable value for PVC. CPVC is the point where the volume fraction of the continuous resin phase is just large enough to form a continuous phase. After this point, if the pigment volume fraction is increased, the properties of the paint film will differ significantly. The properties that are effected are for example; gloss, durability, adhesion and dispersibility. The amount of gloss will decrease the closer PVC is to the CPVC, but other unwanted properties, like corrosion, will increase drastically after CPVC. Hence, the value of PVC should be high, but should not exceed the CPVC value too much or unwanted properties will appear. The value of PVC/CPVC is usually around 0.95 - 1.05 for exterior house paints [17].

2.3.1 Use of Pigments

The pigmentation of a paint has two main functions; provide color and enhance appearance. However, pigmentation can also provide hiding of the substrate. Although, to define the precise color of an object is complex, how color is perceived is for example dependent on the wavelength of the incoming light. Furthermore, the color is also dependent on how visible light is reflected, adsorbed and refracted. Thus, variations in gloss can be perceived as different colors when viewed at different angles. Moreover, alteration in surface or substrate texture can also result in visual color differences [18].

Small pigment particles usually improve the color and hiding ability of a paint. A change in appearance of formulation with time is most frequently caused by pigment flocculation or agglomeration. Pigment flocculation and agglomeration increases the effective particle size and thereby reduce hiding and color development [18]. Consequently, the pigment particles should be finely dispersed to increase hiding and color development to get a homogeneous color, as previously mentioned, see Section 2.3.

2.4 Solid Content

Solid content in paints can be presented in two ways, by *weight solids* or by *volume solids.* Weight solids is the measurement of the remains of paint left after all volatiles have evaporated during curing. Volume solids is the measurement of the volume of solid content that is left when a US gallon (i.e. ca 3.8 liters) of paint's volatile components have evaporated [11]. By using the volume solids value, the amount of surface area which can be painted with a gallon of a certain coating can be calculated. However, the volume solids is harder to measure than the weight solids. Information about solid content is of importance both to the users and to the manufacturers. The users needs to know how much volume of coating is needed for a particular application. While, manufactures need to know the volume in order to determine manufacturing cost. The weight solids is not that useful to users of paint, volume solids is more important [11]. The solid content can affect paint properties such as film durability, coverage and color [19].

2.5 Wood as Substrate

Wood is composed of three main constituents: cellulose, hemicellulose and lignin. The first two compounds are polysaccharides and the last one is polyphenolic. There are also extractives in the wood in low concentrations, which are nonstructural components not linked to the wood cell, e.g. sugars, waxes, phenolics, gallic acid and ionic components [20]. The extractives occur in different parts of the wood. Phenolic extractives are found in the heartwood and bark of the wood, while waxes are found in parenchyma cells [21]. The concentration of extractives is low in wood but does still influence properties such as odor, color and mechanical strength [22, 23]. When wood is exposed to different outdoors conditions, such as moisture, temperature and sunlight, these compounds get modified. The modification can lead to slow erosion, roughening and change of color. Furthermore, the wood can be exposed to various biological attacks, e.g. from insects and fungi. To hinder the degradation of wood from these attacks it is common to use a wood finish, e.g. paint. The paint helps the wood keep its cleanability, appearance, and protects the surface, and reduces moisture in the wood.

During the manufacturing of the protective paint, variation between and within species of wood have to be taken into consideration. Even boards obtained from the same tree can differ in properties. The properties of wood can differ for example texture (e.g. depending on wood type, i.e. softwood or hardwood), grain characteristics (presence of earlywood and latewood), presence and amount of sapwood or heartwood. Additionally, the presence of resins, extractives and oils can also influence the properties of wood. Another significant property that influences the stability of paint on wood is the density of wood. Low density wood shrinks and swells less than high density wood and is therefore more suitable for coatings. Furthermore, shrinking and swelling is dependent on ring formation on the board, how it is cut, vertical or edge-grained surfaces are better than flat-grained. This property is especially important for outdoor paints where different weather can cause swelling in the wood [23]. As previously mention, amount of latewood and earlywood does also affect the properties of wood. Latewood refers to wood with higher density which usually grows later in the growing season and earlywood refers to wood with lower density which usually grows earlier in the season [24]. Hence, if the board has wider, prominent bands of latewood the paint will tend to detach much faster. Another fact that influences the ability of the wood to adsorb the paint, is how the wood is sawn from the log and the surface texture (smooth or rough) [23]. A rough sawn surface will generally adsorb a greater amount of paint material than a planed surface and will consequently have an improved coating performance [25].

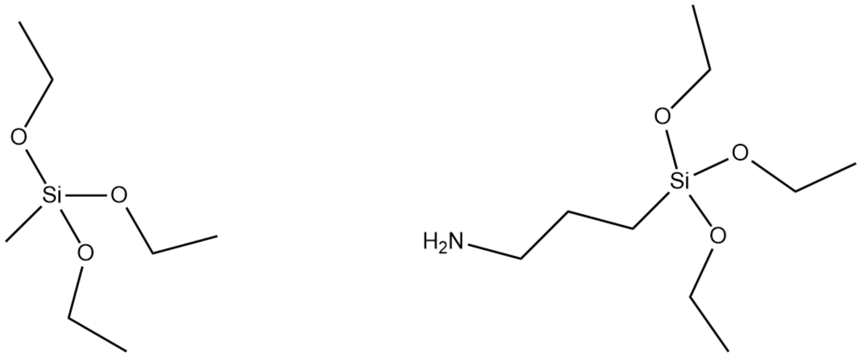
As previously mention, different species of wood have different properties, e.g. different texture, which could affect the properties of the coating. There are two main classes of wood, softwood and hardwood. Softwood does not necessary refer to wood with low tensile strength but to wood that comes from conifers like Scots pine and Norway spruce. The softwoods are usually of low density and of light color. Furthermore, they are often cheaper, softer, easier to work with and grows quicker than hardwoods [26]. Norway spruce, latin *Picea abies*, mainly grows in Europe and the north of Unites States but almost all spruces have a similar anatomy [27]. Norway spruce can also be referred to as *white deal* or *whitewood.* The average density of Norway spruce is 460 kg/m^3 [28]. Scots pine, latin *pinus sylvestris*, mainly grows in Europe and Asia but also in northeastern United States and southeastern Canada [27]. The average density of Scots pine is 550 kg/m^3 [28]. Consequently, Scots pine has a bit higher density than Norway spruce and the wood may swell more. Hardwoods usually refers to broad-leaved trees like oak and beech. The wood is usually of dark color. Furthermore, they are usually denser and have thicker cell walls than softwoods [26].

2.6 Petrified Wood

Petrified wood is a type of fossilised wood. The structure comes from a mineralization process of the woody tissue. Generally, the mineralization process happens before coalification. The wood gets penetrated by mineral salts dissolved in water in an environment with low amount of oxygen which prevents decay [29]. A chemical alteration of organic molecules happens during the process [30]. Crystal structures that can be found in petrified wood are for example silica, pyrite, calcite, goethite and dolomite [29]. Yet, the alteration of organic molecules does not effect the volume of the wood or the morphological characteristics. One form of mineralization of wood is silicification of wood. Wood decay may be favorable for effective silicification of wood. The decay increases porosity and produces functional groups of hydroxyl groups which is thought to be important for the polymerization of silica [30].

2.7 Silanes and Siloxanes and Their Functions as Binders in Paint

Silanes are molecules consisting of silicon and hydrogen. These compounds have the general formula Si_nH_{2n+2}. The simplest and most stable form of silanes is *Silane* which has a tetrahedral structure containing one silicon and four hydrogens, SiH_4 [31]. However, further on when silanes are mentioned, it refers to organofunctional silanes. Organofunctional silanes, which are the common silanes used as adhesion promoters in organic coatings, have the general formula of $X_3Si(CH_2)_nY$. X and Y illustrates the hydrolyzable and the nonhydrolyzable parts of the silane molecules. These parts are very important for film forming and other properties of silane coatings [32]. As seen in Figure 2.1, the nonhydralizable part of carbon atoms can be of different lengths which will give different properties of the molecules. Common organofunctional silanes are e.g. *methyltriethoxysilane* (MTES) and *3-Aminopropyltriethoxysilane* (APTES) [32].



MTES APTES

Figure 2.1: Chemical structure of two common organofunctional silanes, *methyltriethoxysilane* (MTES) and *3-Aminopropyltriethoxysilane*(APTES).

When the silanes come across water the compounds hydrolyze and form silanol groups (SiOH). This makes it possible for the silanes to attach to a hydrated metal surface by Si-oxygen-metal bonds. Furthermore, the hydrolyzed silanes can then form a protective layer on the substrate by self-crosslinking. The silanol groups bond to each other through siloxane bonds (Si-O-Si) [33].

Siloxane refers to organosilicone compounds which are composed of a -Si-O-Si-O-backbone where side groups, *R*, are attached to the Si. These compounds have the general formula R_2SiO. The R-group can be a hydrogen atom or an organic compound which can have different functional groups. Siloxanes can form polymers in which case they are called silicones or polysiloxane [34]. Polysiloxane is made through polymerization of siloxanes. The compounds´ chemical formula is therefore $[R_2SiO]_n$ and thus making it an inorganic polymer but with some organic compatibility. The inorganic part is a silicone-oxygen backbone –Si–O–Si–O- and the organic compatibility comes from organic side groups, R, attached to the silicon atom [35]. Common properties for polysiloxanes are water repellency, heat stability and resistance to chemical attack [36].

Organofunctional silicon compounds are used as silane adhesion promoters in paints, also referred to as *coupling agents.* The coupling agents promote adhesion between the substrate and coating. They are specifically beneficial in order to hinder debonding in humid conditions [23]. Furthermore, the coupling agent can enhance dimensional stability and allow moisture control of the created composite e.g. of the coating and wood [37]. Moreover, the coupling agent provide compatibility with both the organic coating and the inorganic mineral substrate. Figure 2.3 demonstrates the mechanism of the silane coupling agent interacting with the surface of cellulose fibre material [37]. The coupling agent can promote adhesion because silanes are ambifunctional [23]. The ambifunctional property is derived from the structure of the promoters. The general structure of the silane adhesion promoter is usually four substituents attached to a single silicon atom. The most common promoter has a structure of three inorganic-reactive alkoxy groups, e.g. methoxy or ethoxy, and one organic group but it may vary. The structure could for example be two alkoxy groups and two organic groups [38]. This structure enables the silicon promoter to bond to both inorganic and organic phases. The alkoxy group bonds to the mineral substrate and the organic group bonds to the organic coating [23]. In coating materials containing *polydimethylsiloxane* (PDMS), the functional group could also be a long alkyl group and functions as a biocidal derivative. Such functional groups prevents bacterial biofilm formation, reduces bacterial settlement/growth and increases resistance against enzymatic activities. Moreover, other functional groups with those properties could be zwitterionic, fluourinated, containing an amino group or quaternary ammonium [39]. Furthermore, the coupling agent can improve distribution of filler in the material.

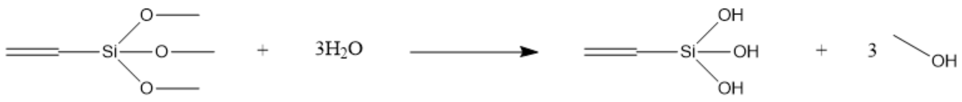


Figure 2.2: The reaction between the coupling agent and water. The coupling agent gets hydrolyzed to a silanol compound.

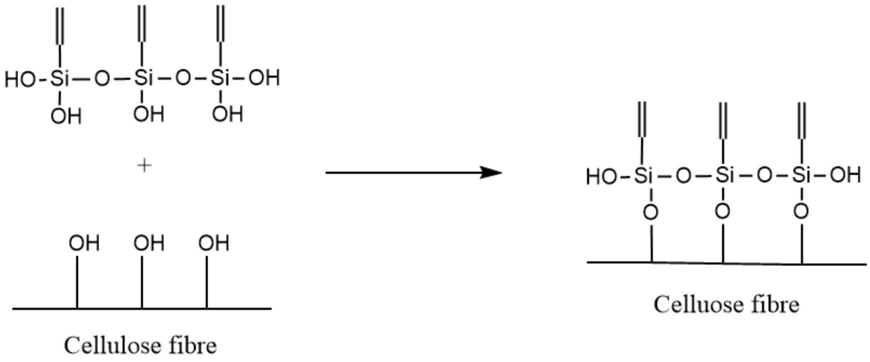


Figure 2.3: The mechanism of the silane coupling agent interacting with the surface of cellulose fibre material

Siloxane is favorable in protective coating. The compound possesses beneficial properties such as being able to crystallize to very strong ceramics and having low glass transition temperature (T_g). Simple silanes do not have these properties. Furthermore, the siloxanes also have thermal stability and oxidation resistance which are high enough to meet the requirements for barrier coatings with rugged bulk properties for reactive substrates in most corrosive conditions. Furthermore, it has also been shown that siloxane in coatings have an anti-fouling property. The surface structure of some siloxanes repel organic- and microsubstances which prevents adhesion and adsorption of these compounds [39].

2.8 Water Based Paints

There are two common ways to formulate a water based paint, either from a dispersion of solid polymer particles or from water-soluble polymers. The first dispersion is a solid in water dispersion and the second is a liquid in liquid emulsion. Solid-liquid dispersions have some benefits in comparison to water-soluble polymer because it is easier to obtain high solids at application viscosities. Further, emulsion polymers, the water-soluble polymers, usually dry too quickly to form tough films. Hence, a solid-liquid dispersion of polymer particles are more common in paints used for domestic and industrial purposes [40]. Note, the water-soluble polymers would not be applicable outdoor since the paint film would be dissolved by rain.

Contrary to solvent based paints, a water based paint needs preservative to prevent from fungal and bacterial growth in the paint bucket. A solvent based paint may need preservative but it is not as common [41].

2.8.1 Acrylic Paint

Acrylic binders are synthetic substances from the petrochemical industry. The acrylate polymer is obtained from raw materials from crude oil or more specifically, generally obtained from free-radical polymerization of acrylate and methacrylate esters [8, 42, 2]. The chemical monomer structure of acrylate is two double bonded carbons connected to an ester functional group (-COOR). The double bond between the carbons is very reactive and can therefore easily polymerize, yielding linear polymers [8, 2].

Acrylate polymers are usually though, soft and rubbery. Generally, the glass transition temperature is much lower than room temperature. Hence, the acrylate polymer will not become brittle unless very cold conditions. Furthermore, other general properties of acrylate polymers are transparency, elasticity, resistance to breakage, high impact toughness and reasonable heat and oil resistance. Furthermore, acrylate polymers have other properties which can be beneficial in paints, they have good capacity of withstanding a weathering process and have ozone resistance due to absence of double bonds in their backbone. However, the properties of acrylate polymers can vary. There are acrylate polymers which can be stiff for example *poly(methyl methacrylate)* (PMMA). The softness or hardness of the polymer is determined by the number of methyl groups [43]. In emulsion paints it is common to use an acrylate copolymer. The copolymer usually contains one component that contributes with hardness and one component which contributes with softness. Consequently, Tg and *minimum film formation temperature* (MFFT) can be designed.

The "hard" component is usually *methyl methacrylate* (MMA) and the "soft" component is usually *butyl-*, *2-ethylhexyl-* or *ethyl acrylate* [44]. The chemical structures for *methyl methacrylate* and *ethyl acrylate* can be seen in Figure 2.4. MFFT is the lowest temperature at which latex coatings will form a continuous polymer film. A coating below MFFT will crack and scatter light. Hence, the film will whiten at this point if it is a pure latex film [45].

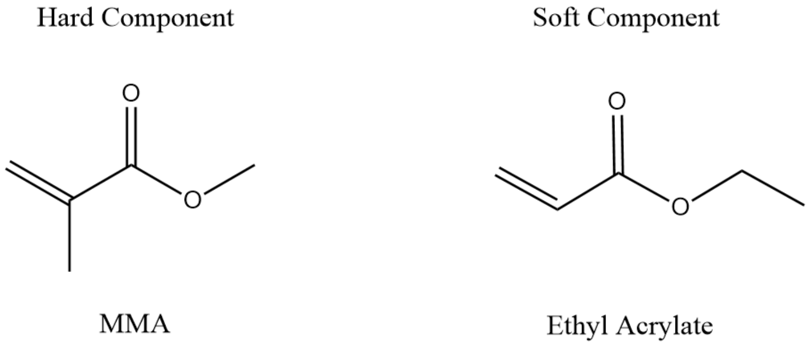


Figure 2.4: Chemical structures for Methyl methacrylate (MMA) and Ethyl Acrylate.

Acrylate paints are usually water based. Benefits of acrylate paints are that they have high covering power, are fast drying and are easy to handle. A disadvantage with acrylic paints is that they contain volatile organic compounds that can be a health hazard or create a unpleasant odor. The volatile compounds are composed of esters, alcohols or *mineral spirits* [46]. Mineral spirits is a general term for hydrocarbon solvents.

2.8.2 Emulsions

An emulsion is a dispersion of two liquids and should not be misinterpreted as a suspension because a suspension is a dispersion of solid substances in a liquid. The two liquids in an emulsion are usually water and an organic liquid. To get the two unmissable liquids to mix, a surfactant is added which will lower the surface tension between the two liquids. The mixture will then form a continuous phase containing one of the liquids and one dispersed phase of droplets containing the other liquid. If the dispersed phase is water and the continuous phase is an organic liquid, it is called an water in oil emulsion (W/O). If the dispersed phase is the organic liquid and the continuous phase is water, it is called an oil in water emulsion (O/W). An emulsion is like a suspension, a thermodynamically unstable system. This means that all emulsions will phase separate with time [41]. Although, emulsion and suspension are two different things, the terms can sometimes be used as synonyms, two examples are *polymer emulsion* and *emulsion polymerization.* Polymer emulsion is in fact a colloidal system where polymer particles are suspended in a liquid [47]. Emulsion polymerization is a common industrial process and the product from such a process are called *latex* [41]. However, latex is defined as colloidal particles suspended in water [7]. Hence, the definitions of a polymer emulsion and the product of an emulsion polymerization are more similar to suspensions. Consequently, a paint which does not include a liquid-liquid dispersion can still be called emulsion in literature due to the method of synthesis. In fact, it is uncommon for commercial formulations to be pure liquid-liquid formulations [47].

2.9 The Synergy Between the Wood Protection and the Surface Protection

The synergy between the Wood Protection and the Surface Protection is not completely proven. However, there are speculations that are based on known chemical behaviours of potassium silicate, silanes and siloxanes and observed properties from usage of the SiOO:X product. In the first step in the SiOO:X product, the Wood Protection is applied to the wood. Wood Protection contains potassium silicate and therefore by extension potassium hydroxide. The hydroxide content is determined by the pH and the potassium ion concentration comes directly from the potassium silicate content. There is a suspicion that the hydroxide ion reacts with acidic sites (e.g. carboxyl groups) in the wood and neutralizes the wood, see Figure 2.5.

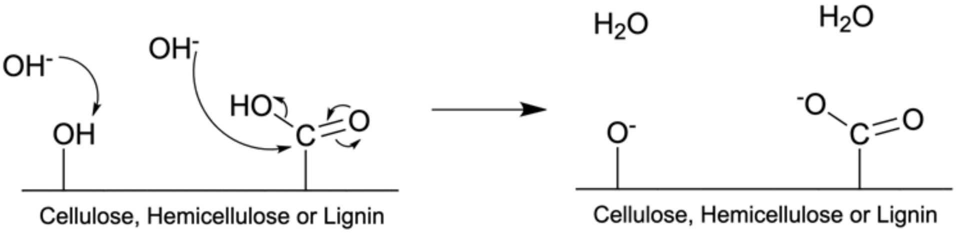


Figure 2.5: The hydroxide ions reacts with the acidic sites in the wood.

The potassium silicate is very reactive and when the Wood Protection is applied to the wood, it penetrates down into the wood where the potassium silicate starts to react. The potassium silicate polymerizes and creates a cluster of discrete, amorphous silica particles. There are two suspicions on how the Wood Protection interacts with the wood. The first suspicion is that that the silicate reacts with the OH groups in the cellulose, hemicellulose and lignin. The second suspicion is that the silicate polymerize inside the wood and that the growth in size makes the Wood Protection stay in the wood. The potassium silicate forms an amorphous cluster of discrete silica particles in the wood. However, the potassium silicate might also be found as monomeric or dimeric silica in the cell walls of the wood. The monomers will constantly dissolve and repolymerize on the surface in the presence of water. The monomers and dimers can therefore be washed away by a water stream, i.e. leaching of the silica. This is especially common in the beginning, after application of the Wood Protection, as a large portion of the silica still is in monomeric form or in the early stages of polymerization. The silica particles can also, mechanically, be washed away if the particles are small, superficial and accessible. They can also be washed away if the fiber they are connected to is removed.

In the next step the Surface Protection is applied to the wood in order to protect the Wood Protection from being washed away. The Surface Protection is comprised of an emulsion with emulsion droplets containing silanes and/or siloxanes dissolved in an organic phase. When the Surface Protection is applied to the board the water surrounding the emulsion droplets starts to evaporate. Consequently, the emulsion droplets burst and the silanes/siloxanes comes in contact with water and the Wood Protection. The water and the Wood Protection contain hydroxide ions which reacts with the silanes/siloxanes and initiate the polymerization. In Figure 2.8, one example is displayed for the catalyzation of the silane with a hydroxy ion. The proposed reaction is a substitution reaction. The reaction is initiated when the hydroxy ion attacks the silicon atom creating a negatively charged silane. The bond breaks between the silicone atom and the alkoxy group. Consequently, the alkoxy group becomes the leaving group and a negatively charged silane is formed. Furthermore, an alcohol is formed as a byproduct. The reaction could also occur as the reaction presented in Figure 2.2 for the coupling agent. However, in that reaction catalyzation was initiated by a metal.

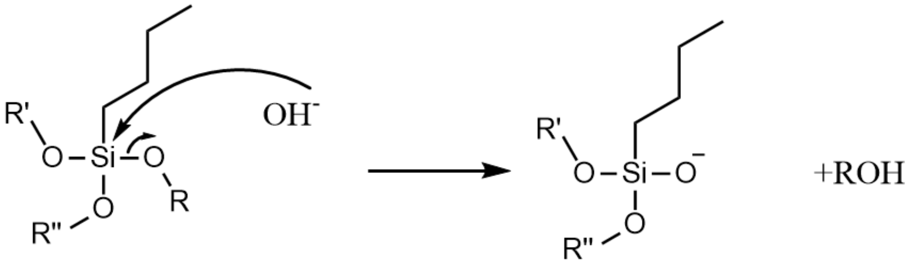


Figure 2.6: Hydroxide ions from water and Wood Protection reacts with silane and forms alcohol.

After the reaction between the hydroxide ion and the silane, the negatively charged silane can attack another silane and polymerization occurs. In Figure 2.7, a proposed reaction between silanes can be seen. The silane ion attacks the silicon atom in the neutrally charged silane. Similarly as in the previous reaction in Figure 2.6, the bond breaks between silicon atom and the alkoxy group. As a consequence, the alkoxy group becomes the leaving group and, in reaction with water, forms an alcohol. The created bond between the silanes is a siloxane bond. Altogether, this displays the polymerization of the silanes.

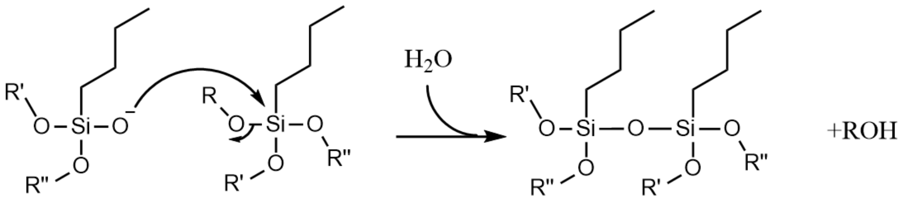


Figure 2.7: The reaction for the polymerization of silanes. A negatively charged silane reacts with a neutrally charged silane and forms an alcohol.

Furthermore, the neutrally charged silanes can also react with the cellulose, hemicellulose or lignin in the wood. An example of that reaction can be seen in Figure 2.8. The negatively charged product from the reaction in Figure 2.5 attacks the silicon in the silane and alkoxy group leaves by a substitution reaction. Thereafter, the alkoxy group reacts with water and forms an alcohol.

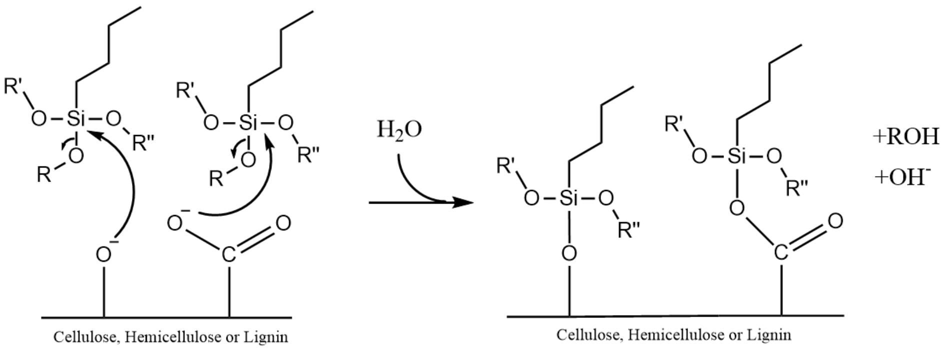


Figure 2.8: Silanes reacting with the negatively charged sites in the wood.

Some silicon binders contain a coupling agent. The coupling agent has two reactive functional groups, see the reactant in Figure 2.2. The coupling agent can react with the cellulose, hemicellulose and lignin in the same way as the silane in Figure 2.8. The coupling agent could form a network on the wood like in Figure 2.3. However, the concentration of coupling agents are low in the binders Sioo Wood Protection uses, thus it is more likely that monomeric coupling agents bond to the wood. The silanes and coupling agent will probably form a film that is partially chemically bonded with the substrate. The film will incorporate the fully reacted siloxanes that will coalesce, in a similar way as latex particles agglomerates, physically adhere to the substrate. Further, the film will be chemically bonded to the wood due to the coupling agents. The layer will be water repellent because the inorganic carbon chains of the silanes will point out from the surface, forming an hydrophobic surface on the wood. The cluster prevents the Wood Protection from being washed away. Thus, there is a synergy between the Wood Protection and Surface Protection. The silica cluster formed from the Surface Protection, locks and hinder the Wood Protection from being washed away. The Surface Protection also creates a coating partially porous and enables important compounds in gaseous form to go through the coating. Important compounds could be e.g. carbon dioxide or water. Carbon dioxide will increase the acidic sites in the wood and water steam will ensure that the process of mineralization and hardening by the Wood Protection can happen.

2.10 Rheology in Paint

Rheology is the study of deformation and flow of materials. The flow properties of paint is an important factor when it comes to application of the paint. During storage, application and film formation, control of flow is important to attain a successful finish. Paint exhibits viscosity change when shear rate is changed [48].

During storage, the paint needs to be kept stable to prevent flocculation, sedimentation and phase separation of the paint. Heavier particles will tend to sink to the bottom of the container due to gravity and particles with lower density than water will flow to the surface [48]. Pigments usually have a higher density compared to water and therefore tend to precipitate due to gravity [9]. To avoid this from happening, the paint should have a viscosity high enough to prevent heavy particles to settle down and lighter particles to flow up. At this stage the paint has high viscosity at low shear rate [48].

Once the paint is applied to the substrate, when it is brushed or rolled, the shear rate increases. The viscosity of the paint drops drastically. This happens in order for the paint to flow out well on the surface. When the paint is applied to vertical surface it will flow due to the influence of gravity. There must therefore be a balance between the flow resistance and ability for the paint to flow out [48].

Further, when the paint has been applied and the shear rate is removed, the viscosity increases again. This prevents the paint from running or dripping on the surface. This viscosity behaviour of the paint is called shear-thinning. The rheology can influence features of the paint such as opacity, film thickness, gloss, adhesion, leveling and tendency for sedimentation of the paint [48].

2.11 Possible Defects of the Coating

A paint should produce a smooth coating after application. Therefore, it is necessary to know about defects that can influence the appearance of the coating. First different surface defects will be presented and thereafter, the importance of adherence and adhesion will be explained.

2.11.1 Surface Defects

Surface defects in coating can form during application, briefly after application and during the curing cycle. The defects are to the major part caused by paint flowing in unintended ways. The paint flow can be affected by surface tension, shear rate and gravity. Defect due to surface tension occur because the surface tension is not uniform on a liquid paint film. In fact, the surface tension can vary a lot on a microscopic level because of compositional changes due to non-uniform evaporation rate, contamination, temperature differences, or gradients. For example, if a specific area on the liquid film has higher surface tension than the surrounding, then the material from the coating will flow from low surface tension to high surface tension. The uneven distribution of material will lead to an uneven coating surface where areas with higher surface tension will have a thicker film. If the paint film is applied on a vertical surface, for example if a wall is being painted, then shear forces caused by gravity can make the paint flow. The unwanted paint flow can thereby cause defects like drips, sags or runs [49]. An example of defects which are most often caused by contamination are fisheyes. Fisheyes are small depressions in the coating surface which look a bit like the craters of the moon [49]. The contamination prevents the coating from wetting that area and from flowing out. An example of contamination could be a liquid with low surface tension like grease or oil, e.g. ethanol has a surface tension of 22.1 mN/m [49, 50]. Moreover, silicon oil from the substrate is a common contaminant [49]. Fisheyes can be prevented with additives with low surface tension or surface energy such as polydimethylsiloxane (PDMS) which have surface energy of 19.8 mN/m at 20 °C [50]. The additives will lower the surface tension of the paint, consequently allowing the paint to wet low surface tension areas and thereby avoiding fisheyes in the coating. Furthermore, sometimes fisheyes can be prevented by increasing the PVC of the coating [49].

2.11.2 Adherence and Adhesion

An important property of the coating is that it does not delaminate from the substrate. This phenomenon can be explained through two approaches, a thermodynamic approach and a termomechanical approach. The thermodynamical approch is to consider adhesion and the termomechanical approach is to consider adherence [51]. The coating will delaminate or crack if the mechanical loading is high enough and depending on temperature.

2.12 Environmental Aspects of Paint

In this section, theoretical background for the environmental assessment will be given. The concept of *Global Warming Potential* (GWP) will be explained. Furthermore, the influence of *Volatile Organic Compounds* (VOC) and cyclosiloxanes in paint will be presented.

2.12.1 Global Warming Potential

Global Warming Potential (GWP) is a tool to be able to compare the global warming impact of different greenhouse gases. GWP is defined as the absorption energy from emission of one ton of gas, compared to the emission of one ton of carbon dioxide. Carbon dioxide is used as a reference. The GWP for carbon dioxide is 1, while the

GWP for e.g. methane is 25. A higher GWP value consequently means that a gas warms the Earth more than carbon dioxide over a certain time period [52].

2.12.2 Volatile Organic Compounds

Volatile Organic Compounds (VOC) are organic compounds which at room temperature are in the gas phase, meaning they have high vapor pressure at room temperature [53]. Products such as cleaning detergents, paints and pesticides contain and emit volatile organic compounds [54]. The release of VOCs indoor can cause health concerns such as irritation, nausea and during long-term exposure cancer. When released in the atmosphere these compounds can react with nitrogen oxide to form ozone and thus contributing to the ground-level air pollution [53].

2.12.3 Cyclosiloxane

Cyclosiloxanes are silicon compounds which are composed of alternating silicon and oxygen atoms in a cyclic structure. The cyclosiloxanes can be used in the synthesis of polysiloxanes where they are used as a precursor [55]. The cyklosiloxanes have an important function in the ring-opening polymerization (ROP) in the synthesis process. In ROP, the reactive center of a polymer chain reacts with the cyclosiloxane and break the bond between the Si and O atoms, hence creating a longer polymer chain. This process creates high-molecular-weight polysiloxanes [56]. The reaction mechanism can be seen below in Figure 2.9, where the curved bond between the two silicon atoms represents the cyclic structure of alternating silicon and oxygen atoms.

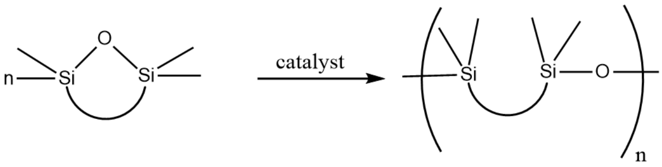
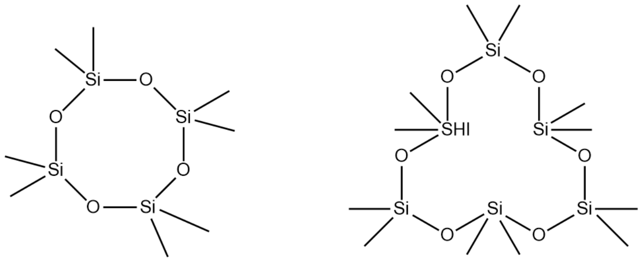


Figure 2.9: Reaction mechanism for ring-opening polymerization of cyclosiloxanes. The curved bond between the two silicon atoms represents the cyclic structure of alternating silicon and oxygen atoms.

There are various types of cyclosiloxanes, where octamethylcyclotetrasiloxane (D4) and dodecamethylcyclohexasiloxane (D6) are two of the most common ones. D4 contains four repeating units of silicon and oxygen atoms in the ring structure, while D6 contains six repeating units. The structure for the D4 and D6 can be seen in Figure 2.10.



D4

D6

Figure 2.10: Chemical structure for octamethylcyclotetrasiloxane (D4) and dodecamethylcyclohexasiloxane (D6).

Both D4 and D6 are used as monomers in the synthesis of polysiloxanes. Consequently, there can be residues of D4 and D6 in the final product. This can lead to the exposure of D4 and D6 to both humans and the environment. Previously studies have showed that D4 and D6 can be toxic to both humans and the environment. D4 has proven to be reproductive toxic, while D6 has been marked *irritant*. D6 have been marked *irritant* because it way cause eye damage or irritation, furthermore the compound may cause long-term harmful effects to the aquatic environment. Both D4 and D6 are hazardous to aquatic environment [57, 58].

3

Methodology and Materials

This chapter provides a description of the methods and techniques used in the project. A motivation for selected methods will be given as well.

3.1 Literature Study

The literature study was performed with by utilizing different databases, e.g. Science Direct and Knovel, since they accommodate many trustworthy sources. Different patents were investigated to get more specific and new information about the technique behind the formulation of paints that Sioo Wood Protection uses. Further, standard models were used to construct tests for the paints. Lastly, *Safety Data Sheets* (SDS) and *Technical Data Sheets* (TDS) about the commercial products, used in the laboratory work, were also studied in order to get information about the content of the products.

3.2 Paint Formulation Procedure

A dissolver from Westerlins was used to mix the ingredients of the paints (i.e. binder, water, thickener and additives), see Figure 3.1. The velocity of the dissolver could be adjusted. Low viscosity paints usually had a velocity from 1000 to 2000 RPM and high viscosity paints usually had a velocity higher than 2000 RPM. The paint buckets used were of metal. Blade, i.e *lenart disc*, used to mix the ingredients were 6 cm in diameter, see Figure 3.2. Note, for the B6 polybinder paints, a lenart disc with a dimater of 4 cm was used. Furthermore, an immersion blender was used instead of a dissolver for B6 monobinder paints due to smaller volume. To mix all pigment formulations a sharper bladed called *Cowels* was used.

In figure 3.1 a picture of the dissolver can be seen.

Figure 3.1: Dissolver and construction used for paint formulation.

In figure 3.2 a picture of the blade used in the dissolver can be seen.

Figure 3.2: Lenart disc used in the dissolver for paint production.

3.3 Viscosity Measurement

To measure the viscosity in paint, a viscometer can be used. In this project a viscometer of *NDJ 5S* type was used. Measurements were made by submerging three different rotors in the paint. For each rotor, measurements were made at four different speeds, 6, 12, 30 and 60 rpm. A 500 ml glass beaker was filled with paint to the 500 ml line. Firstly, rotor 2 was submerged in the glass beaker and viscosity at different speeds were measured. The rotor was lowered so that the marked line on the rotor was in same level as the surface of the paint. Thereafter, the same paint was filled in another 500 ml beaker and measurements were made with rotor 1. The same procedure was made for rotor 3.

3.4 Color Measurement

The color of the paint can be investigated with a dual-beam spectrophotometer. In this project a UltraScan VIS Spectrophotometer was used. The instrument can measure; transmitted and reflected light; and transmission haze. The instrument can additionally function as a reference tool in order to compare the color of the paint with other colors. The spectrophotometer has an optical resolution of 5 nm [59]. The instrument quantifies the color to a scale with certain units, called the Hunter "Lab" scale. The scale include three paarameters, L, a and b. The L-value corresponds to lightness/darkness, the a-value corresponds to redness/greenness and the b-value corresponds to yellowness/blueness [18]. The three parameters can describe any color, see figure 3.3.

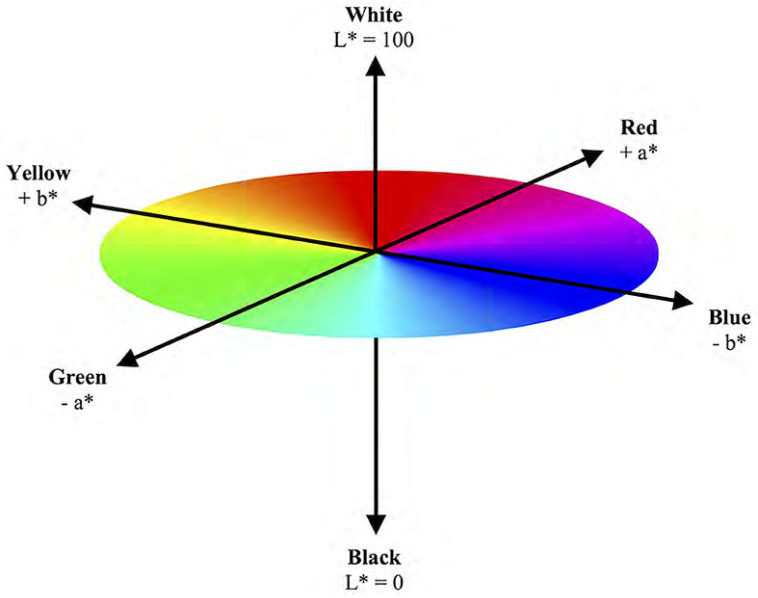


Figure 3.3: A graphical illustration of the Hunter "Lab" scale. The L-value corresponds to lightness/darkness, the a-value corresponds to redness/greenness and the b-value corresponds to yellowness/blueness.

Figure 3.3, demonstrates that the L-value varies between 0 and 100. Furthermore, the figure shows that a positive a-value represents redness and negative value greenness. Lastly, a positive b-value indicates yellowness and a negative value indicates blueness.

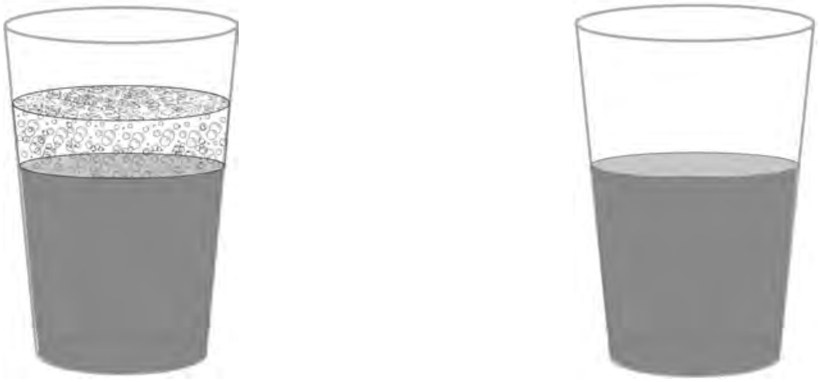
The color of the paints was measured both for the wet paints and the dry paints on the planed boards. For the wet paint, three repeating color measurements were made in the dual-beam spectrophotometer for every paint. Every paint was poured to the brim in a cuvette and was measured, directly afterwards, in the spectrophotometer. It was important to perform the measurement right after the cuvette had been filled otherwise the paint could start to separate. For each measurement, different cuvettes were used. For the dry paints, three repeating color measurements were made for every painted, planed board. The three repeating measurements were performed on different areas of the boards.

3.5 Cross Hatch Adhesion Test

Cross hatch adhesion test is an important test method to measure the adhesion strength of paints. In this test the Swedish standard, SS-EN ISO 2409:2020, was followed [60]. A cross hatch cutter is used with six cutting edges positioned 2 mm apart. The cutter is pressed into the coating of the test board surface making six parallel cuts in the coating. Thereafter, the same procedure is repeated, making six parallel cuts, crossing the first cuts at 90°. This creates a pattern of squares. Further, a strip of tape is placed over the pattern. The tape is then firmly rubbed with one finger and also with a finger nail. In a following step, the tape is removed sharply with an angle of 60°. The adhesion of the paint coating is evaluated by examining the amount of material removed. Based on the amount removed the adhesion of the coating is ranked between 0 to 5, where 0 represents best adhesion and 5 worst adhesion.

3.6 Stability Tests

A common phenomenon in paint is sedimentation during storage of the paint. Larger and heavier particles will tend to sink to the bottom of the paint. Further, smaller and lighter particles will flow to the surface. Pigments usually have a higher density compared to the resin solution and therefore tend to precipitate due to gravity, see Section 2.10. To investigate the stability of the paints, different stability tests were made. The first test, called *foam stability test*, was made to see how much foam the paint contained immediately after it had been produced. In the test, four deciliters of paint were added to a clear plastic cup. The level of volume was marked with a pen. After one week, the level of volume was controlled and the number of centimeters the level had dropped was noted. In Figure 3.4, a visual representation of the foam stability test is presented.



(a) Illustration of the foam stability test immediately after the paint has been produced.

(b) Illustration of the foam stability test after all foam has disappeared.

Figure 3.4: Illustration of foam stability test.

The second stability test, called *stability test*, examined how much the paint separated into different layers and how fast different particles sedimented in the paint. In this test, four deciliters of paint were added to a clear plastic cup after all foam had disappeared in the paint. Thereafter, the level of volume was marked with a pen.

3.7 Texture of Paint Coating

To investigate the texture and the film properties of the paint, a leneta paper was used. In this test, *Byko-chart Opacity 2C* was used which is a clear coated opacity chart consisting of one black and one white area. Hence, a paper with low absorbance. The applicator used was *Model 360* from Erichsen. The applicator creates a 90 mm wide film. Further, the applicator decides the thickness of the film and the thickness can be varied between 30, 60, 90 and 120 μm. By performing this test, lumps in the paint can be detected along with other surface defects such as running, orange peal and fisheyes.

3.8 Gloss Measurement

Gloss from a surface can be measured with a glossmeter, i.e. *Microgloss 60 SER.NO: 985252*, and by following a Swedish standard, SS-EN ISO 2813:2014 [61].The settings of the glossmeter was set to *sample mode* to measure the amount of gloss. The gloss is measured by reflection of light. The glossmeter transmitts a beam of light on the surface and the reflected light is received by a lens at the same angle. Hence, only the reflected light in that angle will be measured. To measure the reflected light, the lens focuses the light beam onto a photo detector. The detector measures the intensity of the reflected light. Gloss is in this case defined as the optical property of a surface to be able to reflect light specularly. A surface will appear more glossy when the specular reflection of objects is more distinct. This happens when the light is reflected more directly from a surface. Consequently, a high-gloss surface will only reflect the light in the main specular direction. A matter surface will not purely reflect the light in the main specular direction but will additionally diffusely scatter the light in all solid angles. The more the light is uniformly scattered into the space, the lower the intensity of the reflected light in the main specular direction will be and the surface appears matter. Hence, the intensity of the reflected light depends both on the angle of the incident light but also on the surface material. A matt surface can appear glossy if the angle of the incident light is smaller. Therefore, the angle of the incident light is specified in a glossmeter. For semi-gloss surfaces a glossmeter with an angle of 60 degrees should be used. The glossmeter measures gloss in *gloss units* (GU) which is not directly convertible to the intensity of the incident light but to the reflection properties of a standard surface. The standard surface is a black, polished glass surface with specified refractive index. The gloss values are defined from 0-100. Where 100 is a highly glossy surface and zero is a very matt surface. [61].

The gloss on leneta paper and on the planed board was measured to get a reference for the gloss measurements. The white part of the leneta paper had a gloss value of *90 GU* on its own when measured without coating. The gloss of the planed boards with different layers of Wood Protection and Surface Protection is demonstrated in Table 3.1. The gloss was first measured on a non-coated planed board. The mean value from 10 measurements were taken from the board. Thereafter, the same measurement was repeated on the board with one layer Wood Protection. After that, the same procedure was repeated with two layers of Wood Protection. Lastly, the measurement was repeated with two layers of Wood Protection combined with one layer of Surface Protection.

Table 3.1: Gloss on planed boards with different layers of Wood Protection and Surface Protection.

Layers of Protection	**Gloss Mean Value [GU]**
No protection layer	12
One layer Wood Protection	9
Two layers Wood Protection	11
Two layers Wood Protection and one layer Surface Protection	4

From Table 3.1, it can be seen that the gloss value decreases on the board with one layer of Wood Protection. The gloss should be lower with two layers of Wood Protection, however the increased gloss could be due to not fully dried areas. In the final step, when Surface Protection has been applied, a clear decrease can be seen. The Surface Protection used is a commercial product from SiOO Wood Protection with a similar shade of gray as the investigated gray paints in this study. Thus, the final value of 4 GU can be used as a reference for a desirable gloss value for all produced paints.

3.9 Solid Content

Prior to testing, caps were tried in the oven to ensure that particles in the material would not evaporate during the experimental procedure. The temperature of the oven was set to 105 °C, and plastic bottle caps of polyethylene were used as containers for the paint. The result showed that the material did not have a significant weight change after heating. Hence, the material did not release particles at heating up to 105 °C. Furthermore, all caps were weighed without paint, with paint and after heating in order to determine weight of the solid content. Paints containing silanes and polymeric siloxanes, in other words monobinder paints containing B1, B3, B4 and all polybinder paints, see Table 4.1, were suspected to need ammonia to make sure that content belonging to the solid content would not evaporate during the heating. Monobinder paints which only contain fully reacted siloxane, in other words paints containing B2, B5, B6 or acrylate, were not suspected to need ammonia. To try the effect of ammonia and to detect possible errors, replicas of three samples were done for each paint. Two out of three samples contained 2 ml ammonia for the paints with silanes and polymeric siloxanes. Whereas, one out of three samples contained 2 ml ammonia for the paints containing only fully reacted siloxane. The samples were weighted every hour during heating until there were no weight change. The last unchanged weight of the sample was used to determine solid content. The calculated solid content which was calculated was the weight solids.

3.10 Weathering Test

A Swedish standard, SS-EN 927-3:2019, was used for conducting the outdoor testing [28]. The standard was used as a template but was tailored to suit the conditions of the project. Outdoor testing was done to observe the resistance of the coating system to natural weathering. The standard is formulated for 12 months but because of the time limit, this outdoor test was proceeded for approximately three months for the monobinder paint and two months for the polybinder paints. The starting date for the weathering test for the monobinder paints was March 29, 2022 and the starting date for the polybinder paints was April 5, 2022. The end date was May 12, 2022 for both monobinder paints and polybinder paints. Two types of boards were used for the outdoor testing; planed Scots pine and fine sawn Norway spruce. The surface texture can influence the absorption of paint, to take this into consideration, the fine sawn and planed boards were used as mentioned. Apart from that, both woods were flat-grained. The paint on the planed wood will degrade faster than on the fine sawn wood, see section 2.5. Hence, a quicker result will be obtained from the first one. To obtain a uniform result, the boards should be selected selectively. Boards should be chosen from the sapwood of the tree, the wood should contain as few defects as possible and no splitting. The coating should thereafter be applied on the convex side of the growth rings. The boards should after coating be hung outside at an angle of 45° to the horizontal and towards the equator [28]. Furthermore, a reference piece should be sawn from the same board as the board taken for the outdoor test, and stored indoors in darkness. This should be done to be able to compare degradation of the paint with its initial state, i.e samples not exposed to weather.

3.11 Accelerated Weathering Test

For the polybinder paints a QUV accelerated weathering tester was used. An accelerated weathering tester replicates the outdoor damage caused by rain, sunlight and dew. After only a few weeks, the QUV can provide a result of the damage on the boards, which otherwise would occur over months or years outdoor. In this project, the accelerated weathering in the QUV was carried out for 150, 300 and 500 hours, according to standard SS-EN 927-6:2018. The accelerated weathering consists of an exposure cycle. The whole cycle lasts for 168 hours and during the cycle the paints are exposed to fluorescent UV lamps, condensation and water spray. In the first step, the boards are exposed to condensation during a 24 h period, see Step 1 in Figure 3.2. Thereafter they are exposed to a subcycle consisting of UV light for 2.5 h and water spray for 0.5 h, see Step 2 and 3 in Figure 3.2. The subcycle, consisting of Step 2 and 3, is repeated 48 times during a 144 h period. After this, the whole cycle is finished and thereafter it starts over with Step 1. The whole cycle is repeated several times until reaching the end time of the test period [62].

Table 3.2: An exposure cycle during a 168 h period consisting of condensation, followed by a subcycle of UV light and water spray. The subcycle, Step 2 and 3, is repeated 48 times before the whole cycle starts over.

Step	Exposure Condition	Duration Time [h]
1	Condensation	24
2	UV	2.5
3	Water Spray	0.5

3.12 Environmental Assessment

For both the monobinder paints and the polybinder paints an environmental assessment was performed. The environmental assessment was limited to only examining the environmental impact of the binders in the paints, excluding the environmental impact of other components in the paint. The scope of investigation began where the binders were produced and ended when they arrived to Sioo Wood Protection i.e. step A1 and A2 in a *Life Cycle Analysis* (LCA). Data for the environmental assessment was given by an LCA consultant to Sioo Wood Protection. The database used by the LCA consultant was *Ecoinvent 3.8* and the calculations were performed using *SimaPro 9.3.0.3.* Ecoinvent 3.8 is a Life Cycle Inventory database which covers many different sectors, e.g. agriculture, chemicals and plastics, energy, transport, waste treatment and water supply [63]. SimaPro 9.3.0.3. is a LCA software designed for LCA calculations [64].

Firstly, the *Global Warming Potential* (GWP) impact was calculated for 1 kg of each binder. This was performed by listing all ingredients in the binder and the concentration of each ingredient in percent. Data for this could be found in the *Safety Data Sheet* (SDS) for the binder. The percent of all ingredients were added together and if it did not add up to 100%, water was added. Thereafter, the concentrations of all ingredients were converted to kilograms by dividing the percent of each ingredient with 100. The quantity of each ingredient was then multiplied with the GWP value for climate change for each specific ingredient. Data for GWP impact for climate change was given by the LCA consultant. Further, the GWP impact for all the ingredients were added together and this gave the impact of 1 kg of the binder. Thereafter, the environmental impact for the binders in the monobinder and polybinder paints were calculated. In the monobinder paints, the mass of binder in each paint was multiplied with the GWP value for 1 kg of that specific binder. For the polybinder paints the mass of each binder was multiplied with the GWP value and thereafter, the GWP values for all binders were added together.

The next step in the environmental assessment was to calculate the impact for each binder regarding to transportation. Depending on the place of manufacturing there were different types of transportation with diverse environmental impact. Data for the different transportation types was given by the LCA consultant. Firstly, the place of manufacturing for the silanes and siloxanes was investigated. An approximate distance from the place of manufacturing for the silane/siloxane to the manufactuing place for the binder was estimated by using Google Maps. The mass of silane or siloxane used in each paint was multiplied with the GWP value for the transportation for that distance. Secondly, the place of manufacturing for the binders was investigated and the distance was approximated from the manufacturing site to Sioo Wood Protection. The mass of the binder used in each paint was multiplied with the GWP value for the transportation for that distance. Further, the impact for the transportation for both the silane/siloxane and the binder was added together and a total impact for transportation was obtained.

4

Experimental Procedure

This chapter provides a chronological description of the work process. First, the work process connected to the monbinder paints will be described and thereafter the work process for the polybinders. The work process includes preparation and testing of the formulated paints.

4.1 Monobinder Paints

The work procedure began by investigating which binders that were available at the company. Thereafter, the different binders were listed with their properties, hazards, silicon component and content. The categorization was done in order to visualize which binders that were most suitable for usage in the project. From the literature study and discussions with the company, six binders were selected, see Table 4.1. Moreover, acrylate binder was decided as a reference.

Table 4.1: Selected binders for the project and binder content

Binder	Type of Silicone Compound	Coupling Agent of silane/siloxane	Residue
B1	Silanes and polymeric siloxanes	Silane	D6
B2	Fully reacted siloxane	No	No
B3	Silanes and polymeric siloxanes	Siloxane	D4
B4	Silanes and polymeric siloxanes	Siloxane	D4
B5	Fully reacted siloxane	No	No
B6	Fully reacted siloxane	No	No

The residues seen in Table 4.1, are derived from the polymerization of siloxane. For more detailed information of each binder, see Appendix A.

4.1.1 Recipe

When the six different binders had been selected a recipe was created for the monobinder paints. Firstly, two levels of PVC were determined based on theory about low-PVC-paints for exterior durability. One lower and one higher value were chosen in order to see how the PVC would affect different properties. The PVC levels were determined to 20% and 30%. The pigment volume was constant and the amount of binder was adjusted to get the different PVC's. Then, a recipe was created which worked as a template for all recipes made for the monobinder paints. Due to company discretion, the template recipe is not included in this report. However, the components in the recipe can be seen in Table 4.2.

Table 4.2: Components in the template recipe for the monobinder paints.

Paint components
Water
Preservatives
Thickener
Dispersant
Binder
Pigment; Carbon Black, Titanium dioxide and Iron oxide

The template recipe was divided into different steps, where a few steps could be prepared in advance and used in several paints. The steps prepared in advance could be formulations containing e.g pigment, thickener or preservatives. These formulations needed to be reproduced several times during the project.

Once these formulations had been prepared, a specific recipe for every paint was created based on the template recipe. For each selected binder, six paints were manufactured with three colors and two different PVC's, 20% and 30%. The colors of the paints were black, yellow and gray. Altogether, two yellow, two black and two gray paints with different PVC's were manufactured for each selected binder. An illustration of all paints manufactured for one binder can be seen in Figure 4.1.

Figure 4.1: For one binder six paints were manufactured, two yellow, two gray and two black paints with PVC 20% and 30%, respectively.

4.1.2 Paint Formulation

When mixing each paint the total volume was set to two liters. The paint was mixed in a five liters metal bucket with a dissolver. All components were added to the bucket while stirring. Once each component had been added, the velocity of the mixing was adjusted in order to obtain a vortex in the mixture.

Moreover, for binder B6 the total volume was set to 200 ml compared to the other binders with two liters. This was due to low amount of binder available at the company. However, the B6 paints contained the same components as the other paints, see Table 4.2. The B6 paints were mixed in 600 ml plastic container with an immersion blender. Due to the intensive mixing with the immersion blender, the mixing times were cut shorter for the B6 paints. All components were added to the container while stirring.

4.1.3 Testing of Wet Paint

A foam stability test was taken immediately after the paint was produced, see Section 3.6. After a few days, when the foam in the paint had disappeared, *the stability test* was prepared, see section 3.6 . All of the stability tests were left on a shelf without moving the cups during the whole project time. The cups were marked with date and time when they were filled. Furthermore, viscosity measurement, color measurement and paint application on leneta paper was performed on the wet paints, see Sections 3.3, 3.4, 3.7.

4.1.4 Preparation of Boards and Testing of Dry Paint

The monobinder paints were painted on the boards for outdoor testing, cross hatch testing, gloss measurement and color measurement. The boards were chosen carefully to get a uniform result. Boards from the sapwood with as uniform surfaces as possible, with other words, surfaces with low amount of defects, were chosen. Firstly, the boards were coated with two layers of Wood Protection, for the planed surface 75 g/m^2 was applied in each layer and for the fine sawn surface 140 g/m^2 was applied in each layer. The Wood Protection was SiOO:X own product, called *Wood Protection Industry* and was not pigmented. A scale was used to get the correct application amounts. Only the front of the board and the sides of the boards were painted, not the backside or the end grains. The front side was the convex side to the growth rings of the wood. The coated layers were left to dry for approximately 2-4 hours. Lastly, a layer of the formulated monobinder paint was applied with the same amount as for one layer of Wood Protection, with other words, 75 and 140 g/m^2 respectively. The monobinder layer was left to dry. The planed boards were sawn into three pieces: a reference piece of five cm, one piece for cross hatch, color and gloss measurement of 10 cm and one piece of 50 cm for outside testing. No cross hatch was executed on the fine sawn boards so those boards were only sawn into a 5 cm reference piece and a 50 cm piece for outdoor testing. Each piece had an approximate width of 12 cm and a thickness of two cm. The boards for outdoor testing were coated with silicon at the end grains to prevent from unwanted impact from the uncoated ends. All boards of 50 cm were hung outside at a slightly lower degree than 45 and towards the equator. The condition of the paint on the boards was then documented as often as possible.

The paints were also applied on leneta paper for gloss measurement and to observe film properties. Gloss values from the paint films were taken from the white area of the leneta paper. Three values were taken from different places within the white area and a mean value was calculated to get an average gloss value for the whole area. Gloss was also measured on the 50 cm planed boards for outdoor testing and on the 10 cm boards. From the outdoor boards, before they were hung outside, a mean value of 20 values from different places of the board was taken. From the 10 cm boards a mean value of only 10 values were taken due to the painted area being smaller. All values were taken from areas with as few defects as possible. The coating was uneven in some cases which could have affected the result. In addition to gloss measurement, color was measured on the 10 cm boards with the spectrometer.

Three values from different areas of the board were taken. Areas with defects were avoided. Cross hatch tests were used to determinate adhesion strength of the paint. Two cross hatch tests were taken from each 10 cm board.

4.2 Polybinder Paints

After evaluating the monobinder paints and discussing with the company, three binders where chosen as the most interesting binders to proceed with. The three selected binders were B2, B5 and B6. The selection of binders for polybinder paints will be explained in the Discussion section, see Section 6.2.8.

4.2.1 Recipe

After the three binders had been selected a recipe was created for the polybinder paints. PVC level was set to 25% due to it being the mean between the previous PVC's tested, 20% and 30%, and in order to reduce paints produced and tested. The pigment volume was constant and the amount of binder was adjusted to get the right PVC. Furthermore, the pigment volume was the same as for the monobinder paints. It was decided to produce only gray paints at two different levels of acrylate content. One level where the acrylate content had been partially substituted and one level where it had been completely substituted with one of the selected binders. Further, a recipe was created which was used as a template for all the recipes made for the polybinder paints. Each selected binder was investigated in polybinder paints with a combination of acrylate and binder Bx. Binder Bx is a silane-based emulsion. The acrylate and binder Bx were kept at a constant level while the selected binder was adjusted to get PVC 25%. Due to company discretion the template recipe is not included in this report. However, the components in the recipe can be seen in Table 4.3

Table 4.3: Components in the template recipe for the polybinder paints.

Paint components
Water
Preservatives
Thickener
Dispersant
Binders; Acrylate, Bx and selected binder
Pigment; Carbon Black and Titanium dioxide
Coalescing agent

The recipe where the acrylate content had been completely substituted was arranged in the same way as for the recipe where the acrylate content had been partially substituted. However, in this recipe the acrylate content and coalescing agent had been removed. The coalescing agent is only used when acrylate is present in the paint.

4.2.2 Paint Formulation

When manufacturing each polybinder paint, the total volume was set to two liters. The procedure was the same as for the monobinder paints, see Section 4.1.2.

However, for the polybinder paints with binder B6 the total volume was set to 1388 ml. This was due to the quantity of binder B6 available at the company was lower compared to the other binders. The B6 polypaints were mixed in a 2.7 liters plastic container with diameter of 12.65 cm. Further, a smaller lenart disc with diameter of 4 cm were used to mix the paints. However, the mixing procedure was still the same as for monobinder paints, see section 4.1.2.

4.2.3 Testing of Wet Paint

The viscosity measurements, color measurements, stability tests, and paint application on leneta for the polybinder paints were made in the same way as for the monobinder paints, see sections 3.3, 3.4, 3.6 and 3.7.

4.2.4 Accelerated Weathering Test

For the polybinder paints, a QUV accelerated weathering tester was used, see section 3.11. Twenty-eight longitudinal-grained Scots pine fine sawn boards were prepared with dimensions 300 x 68 x 16 mm. To every board, 140 g/m^2 of Wood Protection was applied. The boards were painted on a scale to be able to get the right amount of Wood Protection and the sides of the boards were covered with tape to avoid Wood Protection from entering the end grains of the boards. Thereafter, the boards were left drying for 2 hours. Furthermore, one more layer of 140 g/m^2 Wood Protection was applied and the boards were left drying for additional two hours. Each polybinder paint was then applied to four boards with a layer of 140 g/m^2. The paints were left drying for two hours. Further, the tape on the sides of the boards was removed and the boards were weighed. Each board was marked with a number from one to twenty-eight, and labeled with the name as the paint. Thereafter, the boards were sent to RISE in Stockholm for testing in the QUV accelerated weathering tester, except for seven boards that were stored as references.

All 21 boards were put in the QUV accelerated weathering tester from the beginning, thereafter seven boards were taken out after 150 hours, seven boards after 300 hours, and the last seven boards after 500 hours. Furthermore, the boards were sent back to Sioo Wood Protection and were examined and compared with the reference boards.

4.2.5 Preparation of Boards and Testing of Dry Paint

The outdoor boards for the polybinder paints were prepared in the same way as the monobinder paints, see section 4.1.4. However, the polybinder boards were only hung for approximately two months because these paints were prepared after the monobinder paints. Cross hatch testing, gloss and color measurement were measured in the same way as for the monobinder paints, see section 4.1.4. However, gloss was only measured on the 10 cm boards, not the 50 cm outdoor boards.

5

Results

This chapter provides a description of the results from testing of paint properties of monobinder paints and polybinder paints. Furthermore, results from the environmental assessment will be given.

5.1 Monobinder Paints

In this section, the result from testing of the monobinder paints is displayed. Hence, testing of paints containing binder B1, B2, B3, B4, B5, B6 or acrylate binder. The paints containing the acrylate binder are reference paints to the paints containing the other binders. Properties that were investigated were storage stability, viscosity, color, texture, gloss, solid content and adhesion durability.

5.1.1 Stability Test

In Table 5.1, the proportion of foam decrease of the monobinder can be seen. *Yellow B1 20%* and *Black B1 20%* had decreased the most with 83% and 70%. Hence, for these paints some sort of defoamer could be needed. The paints which had decreased the least were a few of the paints containing binder B2 and B4. They exhibited a foam decrease of 0%.

Table 5.1: The proportion of foam decrease in the foam stability test for monobinder paints.

Paint	**Foam Decrease [%]**	**Paint**	**Foam Decrease [%]**
Gray B1 20%	57.14	**Black B4 20%**	0
Gray B1 30%	25	**Black B4 30%**	0
Black B1 20%	70.00	**Yellow B4 20%**	27.27
Black B1 30%	40	**Yellow B4 30%**	9.52
Yellow B1 20%	83.33	**Gray B5 20%**	27.27
Yellow B1 30%	27.27	**Gray B5 30%**	31.82
Gray B2 20%	9.52	**Black B5 20%**	42.45
Gray B2 30%	18.18	**Black B5 30%**	38.10
Black B2 20%	0	**Yellow B5 20%**	28.57
Black B2 30%	19.05	**Yellow B5 30%**	31.43
Yellow B2 20%	19.05	**Gray B6 20%**	11.11
Yellow B2 30%	20	**Gray B6 30%**	28.57
Gray B3 20%	6.82	**Black B6 20%**	39.47
Gray B3 30%	8.93	**Black B6 30%**	12.50
Black B3 20%	4.42	**Gray Acrylate 20%**	29.59
Black B3 30%	7.50	**Gray Acrylate 30%**	17.48
Yellow B3 20%	4.76	**Black Acrylate 20%**	18.00
Yellow B3 30%	4.55	**Black Acrylate 30%**	21.05
Gray B4 20%	0	**Yellow Acrylate 20%**	31.58
Gray B4 30%	0	**Yellow Acrylate 30%**	19.05

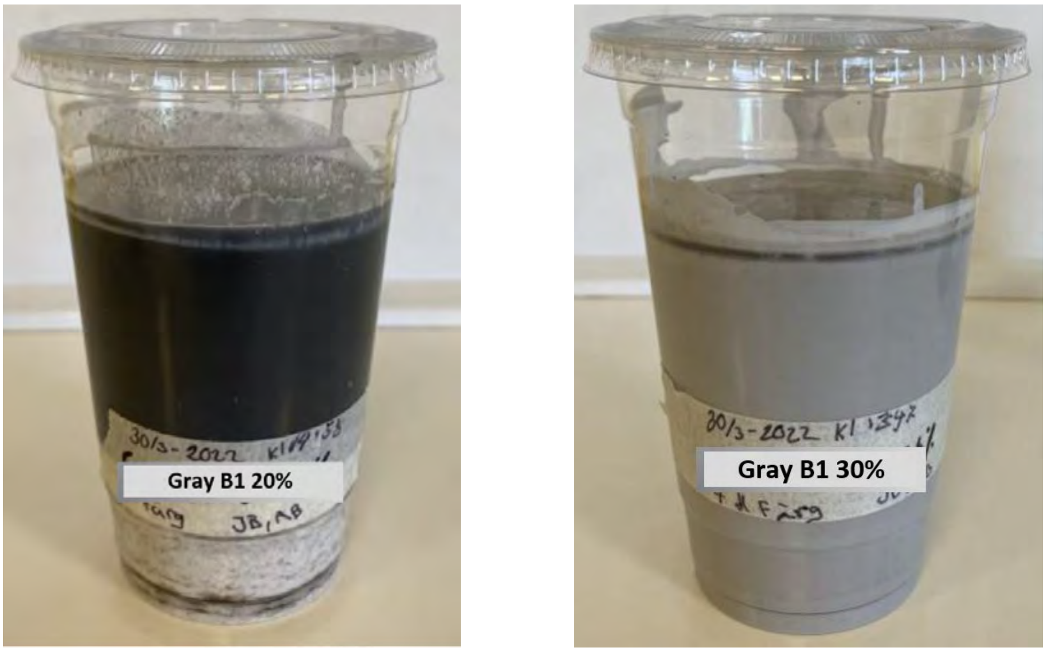
Table 5.2 demonstrates the mean value for the proportion of foam decrease in the foam stability tests for monobinder paints with the same binder.

Table 5.2: The mean value for the proportion of foam decrease in the foam stability tests for monobinder paints with the same binder.

Binder	**Mean Foam Decrease [%]**
B1	50
B2	14
B3	6
B4	6
B5	33
B6	23
Acrylate	23

Monobinder paints containing binder B1 had the highest mean foam decrease of all monobinder paints. Whereas, monobinder paints containing binder B3 or B4 had the lowest mean foam decrease. Although, considering the foam decrease of the individual monobinder paints containing binder B4, the yellow paints stood out, see Table 5.1. The yellow monobinder paints containing B4 had foam decrease of approximately 10% and 27%. Whereas, the black and gray paints did not decrease at all.

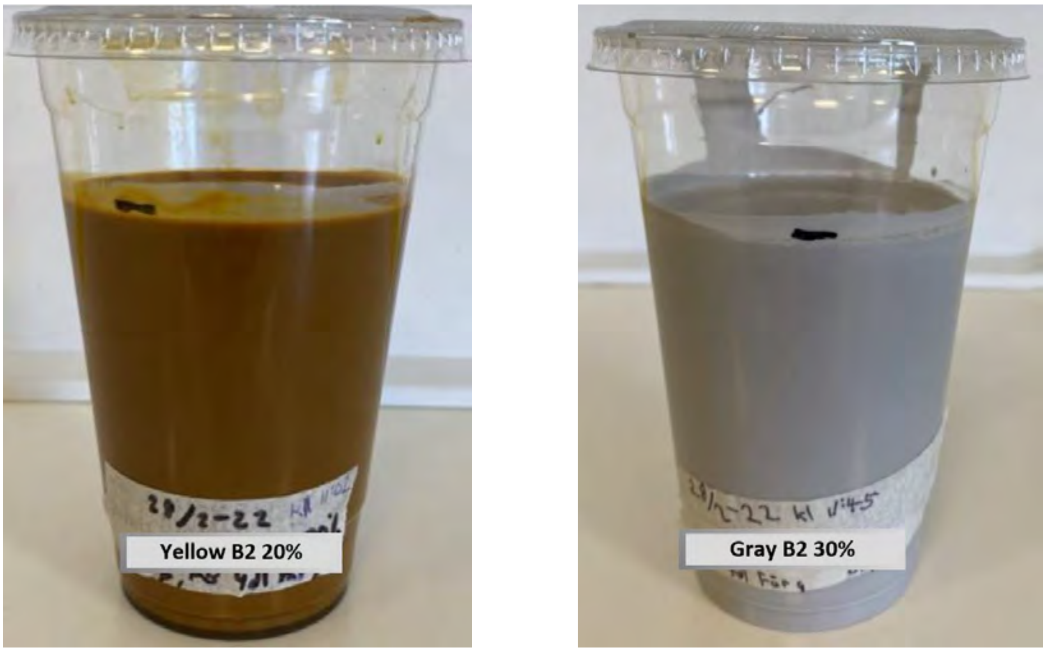
The final result of the stability test for the monobinder paints with binder B1 was noted after approximately one and half month. In Figure 5.1, the stability test for the gray monobinder paints with binder B1 can be seen. For the monobinder paints with B1, the gray paints and one of the yellow paints had separated by pigment. The black pigment in *Gray B1 20%* had separated the most, a wide black layer could be seen at the surface and a white layer underneath, see Figure 5.1a. *Gray B1 30%* had lower phase separation, only a thin black layer could be seen at the surface, see Figure 5.1b. For the two yellow paints, only one of the paints had separated and the color of the bulks were different. *Yellow B1 20%* had a lighter bulk color than *Yellow B1 30%* and light yellow pigment had separated to the surface in a thin layer. *Yellow B1 30%* was visually homogeneous and had no phase separation. However, the black paints with binder B1 were homogeneous. A general feature for the B1 monobinder paints was pigment separation.



(a) Stability test for *Gray B1 20%* **(b)** Stability test for *Gray B1 30%*

Figure 5.1: Stability tests for the gray monobinder paints with binder B1. The stability tests had been stored for 44 days without interference, and the paints were produced 52 days ago.

The final result of the stability tests for the monobinder paints with binder B2 were noted after approximately two and a half month. In Figure 5.2, the stability tests for *Yellow B2 20%* and *Gray B2 30%* can be seen. Both stability tests of *Yellow B2 20%* and *Yellow B2 30%* were similar and homogeneous in color. However, in *Yellow B2 20%* there was a dark layer of sediment at the bottom of the test and small tiny dots of darker pigment on the surface. Regarding the gray paints with binder B2, they had similar appearance. Both gray paints were homogeneous in color, but had small, white dots on the surface. The black paints with binder B2 were also homogeneous in color. For *Black B2 20%*, the paint seemed to have exhibited creaming. However, not to the same extent as for *Gray B4 30%*, see Figure 5.4a.

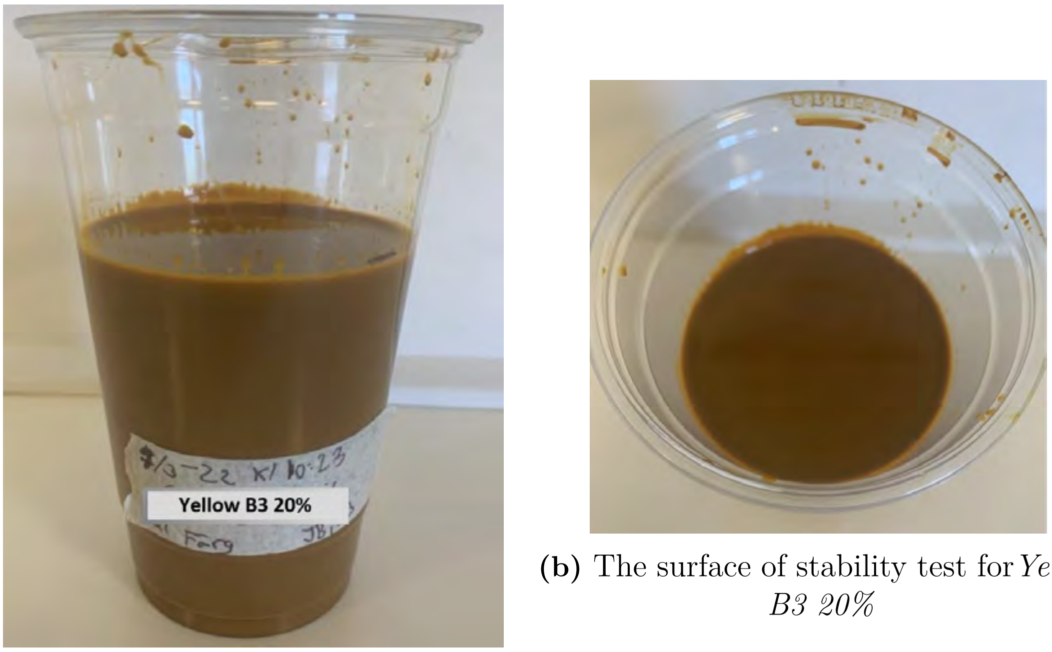


(a) Stability test for *Yellow B2 20%*,. A darker shade of paint can be seen at the bottom of the test.

(b) Stability test for *Gray B2 30%*.

Figure 5.2: Stability tests for *Yellow B2 20%* and *Gray B2 30%*. The stability tests had been stored for 74 days without interference, and the paints were produced 79 days ago.

The final result of the stability test for the monobinder paints with binder B3 were noted after approximately two months. The stability tests of the paints with binder B3 had a homogeneous color. The stability test for *Yellow B3 20%* can be seen in Figure 5.3. The gray paints were similar in appearance to *Gray B2 30%* in Figure 5.2b. Although, the gray paints with binder B3 had few spots of dark gray pigment on the surface. The yellow and black paints had an even color on the surface. Overall, the stability tests with binder B3 appered to be stable after two months.

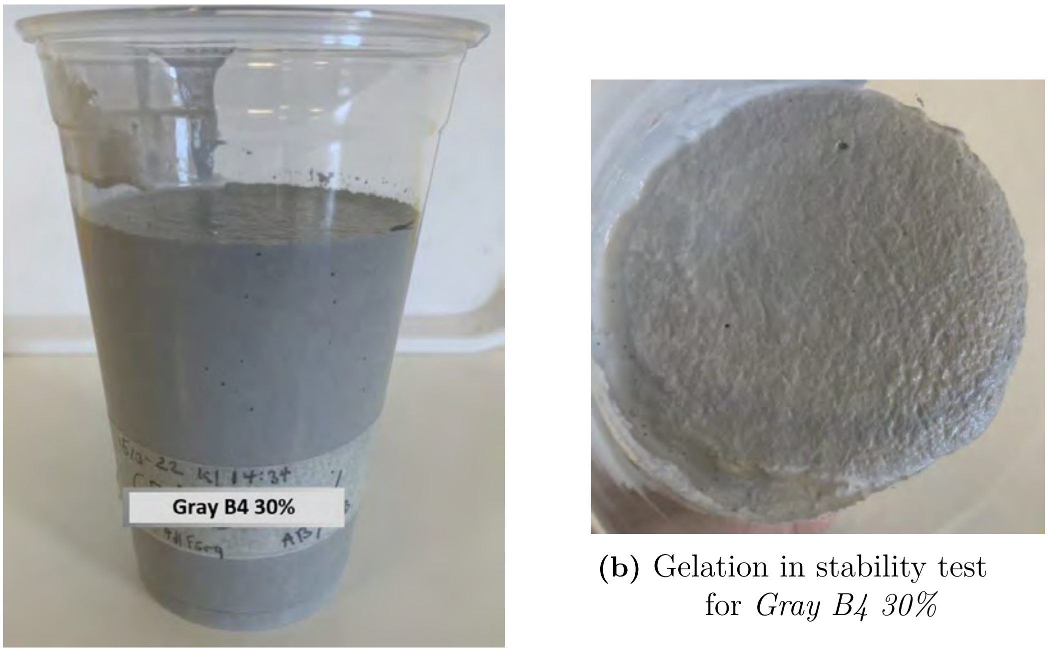


(a) Stability test for *Yellow B3 20%*

(b) The surface of stability test for *Yellow B3 20%*

Figure 5.3: Stability test for *Yellow B3 20%*. The stability test had been stored for 67 days without interference, and the paint was produced 71 days ago.

The final result of the stability tests for the monobinder paints with binder B4 were noted after approximately two months. Figure 5.4 demonstrates the stability test of *Gray B4 30%*. Furthermore, the figure demonstrates an unexpected result, gelation was observed in *Gray B4 30%*, see Figure 5.4b. In fact, both gray stability tests displayed gelation. For the black paints gelation was also observed, however not to the same extent. On the contrary, the yellow stability tests did not display gelation and were rather low viscous in comparison to the other stability tests with binder B4.



(a) Stability test for *Gray B4 30%*

(b) Gelation in stability test for *Gray B4 30%*

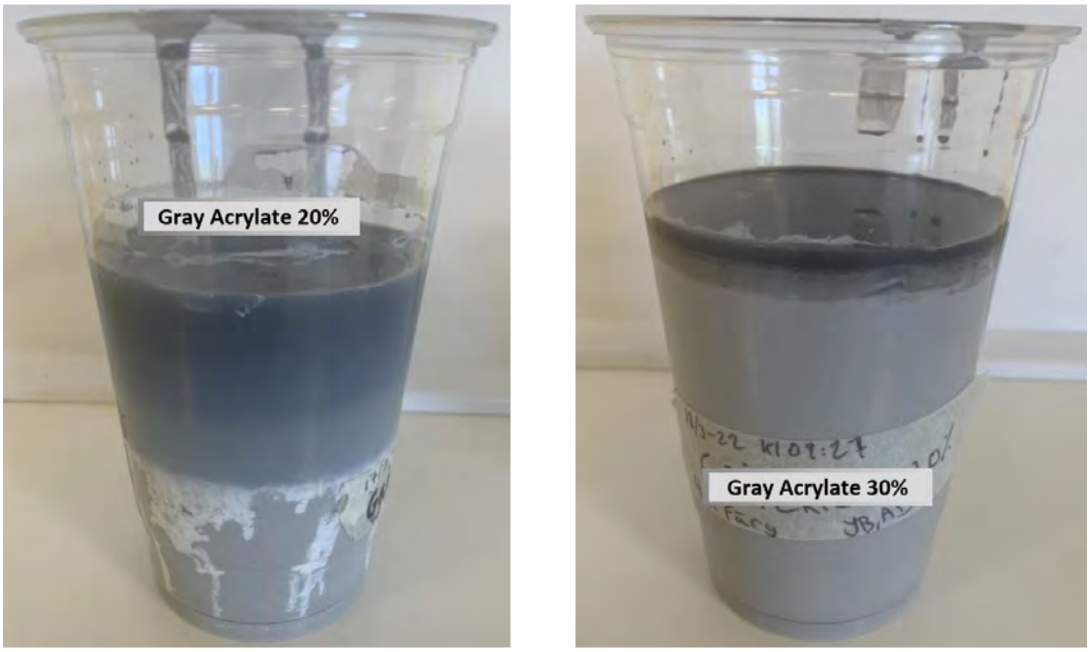
Figure 5.4: Stability test for *Gray B4 30%*. The stability test has been stored for 59 days without interference, and the paint was produced 71 days ago. Gelation was observed in the test.

Regarding color of the stability test containing binder B4, all stability tests had a quite homogeneous color in the bulk, although one yellow stability test had a lighter yellow color in a layer on the surface.

The final result of the stability tests for the monobinder paints with binder B5 were noted after approximately 2 months. All stability tests had homogeneous color, similar to the appearance of *Yellow B3 20%* in Figure 5.3. Worth mentioning is that these stability tests had been standing close to a window, consequently they had been exposed to direct sunlight. Water drops could be seen on the lids and on the sides of the top of the plastic cups. Furthermore, the yellow and black stability tests had a transparent layer on the surface which resembled water.

The final result of the stability tests for the monobinder paints with binder B6 were noted after approximately 2 months. There were only gray and black stability tests for this binder, as previously mentioned, and they all had an homogeneous color.

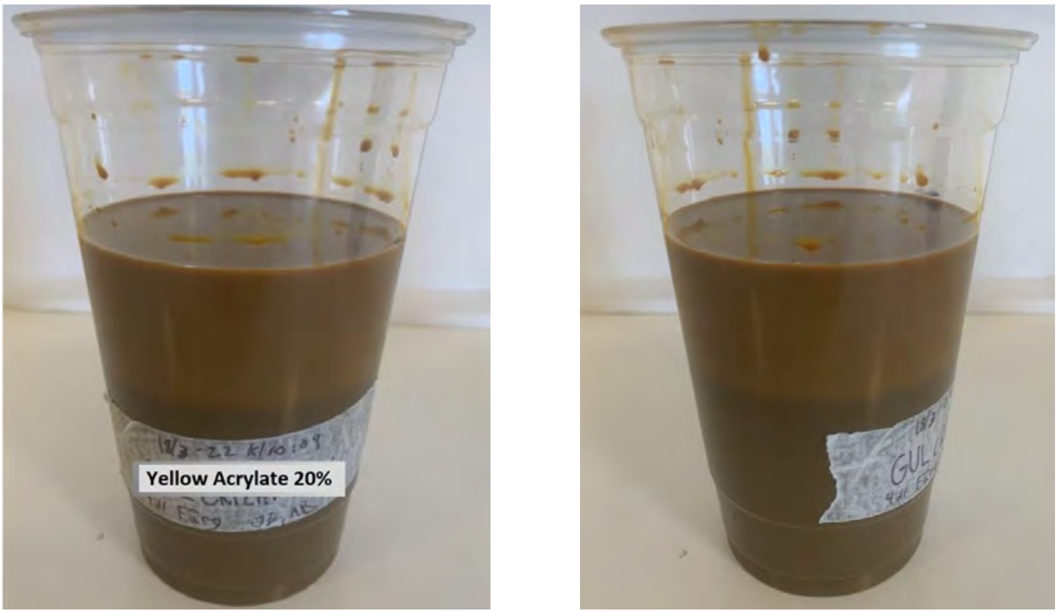
The final result of the stability tests for the monobinder paints with acrylate binder were noted after approximately 2 months. The result from the stability tests with the gray paints can be seen in Figure 5.5. *Gray Acrylate 20%* displayed quite extensive phase separation and white streaks could be seen at the sides of the lower part of the cup, see Figure 5.5a. Darker pigment had separated to the upper part in the stability test, and had a more blueish shade than the other gray stability tests with other binders. Furthermore, a wood stick was lowered into the paint and used to make a prediction of the viscosity of each layer. The upper layers felt more low viscous, there were less resistance when the stick was slowly moved from side to side, and the bottom layer with the white streaks felt more viscous, there was more resistance to movement. The pigment separation in *Gray Acrylate 30%* looked slightly different, see Figure 5.5b. There was only one distinct separation of pigment at the surface, a thin layer of darker pigment. However, the dark shade did also have a blueish shade.



(a) Stability test for *Gray Acrylate 20%*. **(b)** Stability test for *Gray Acrylate 30%*.

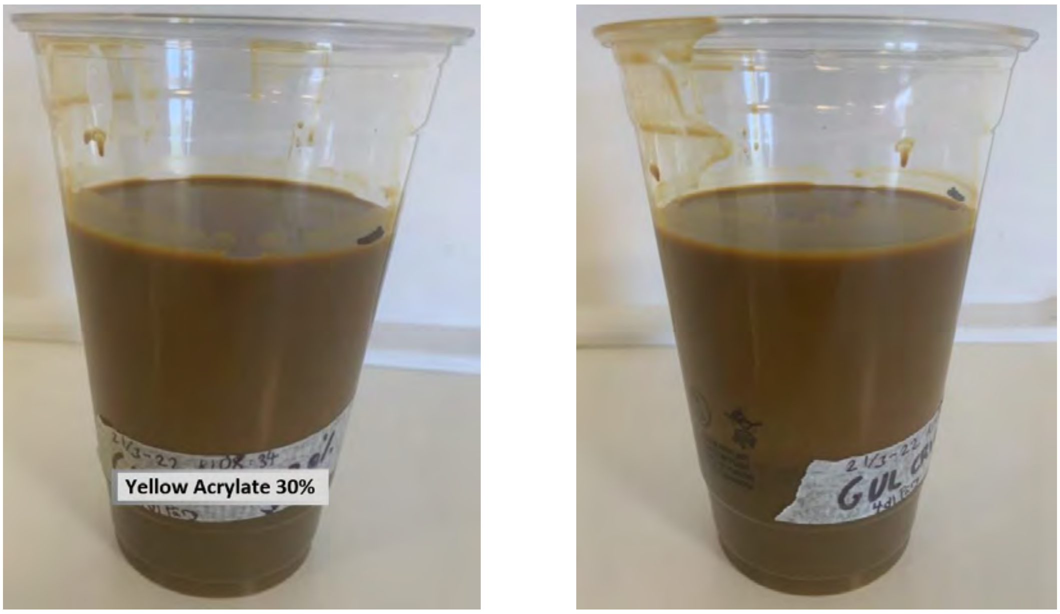
Figure 5.5: Stability tests for the gray monobinder paints with acrylate binder. The stability tests had been stored for 56 days without interference, and the paints were produced 59 days ago.

Moreover, there was also pigment separation in the yellow stability tests with acrylate binder, see Figure 5.6. Darker pigment had separated to the bottom of the cups and lighter pigment to the surface. *Yellow Acrylate 30%* had separated slightly more than *Yellow Acrylate 20%*. Lastly, for the black paints no pigment separation was observed and the paints had a homogeneous color.



(a) Stability test for *Yellow Acrylate 20%*.

(b) Pigment separation in the stability test for *Yellow Acrylate 20%*.



(c) Stability test for *Yellow Acrylate 30%*.

(d) Pigment separation in the stability test for *Yellow Acrylate 30%*.

Figure 5.6: Stability tests for the yellow paints with acrylate binder. The stability tests had been stored for 56 days without interference, and the paints were produced 57 days ago.

To sum up, the result of stability tests containing the monobinder paints gave varying results. There were many tests which displayed phase separation, e.g. the stability tests with binder B1 and acrylate. Noteworthy were the stability tests containing binder B3, B5 and B6 which did not display phase separation. Moreover, most stability tests with binder B2 had not phase separated either. Furthermore, an interesting result was obtained in the stability tests with binder B4, where gelation was observed.

5.1.2 Viscosity

Generally, for all monobinder paints, the viscosity measurements displayed that the dynamic viscosity decreased with increasing sheer rate, see Appendix B. This means all monobinder paints were shear thinning. In Figure 5.7, the viscosity for the reference paints with acrylate can be seen. The dots in the graph represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line to demonstrate the decrease of viscosity with increasing shear rate. The color of each trend line in the graph represents the color of the paint. For every color there are two paints, one with PVC 20% and one with 30%. All paints with acrylate had quite low viscosity. Comparing the paints with PVC 20% and PVC 30%, it can be seen that the paints with PVC 30% displayed higher viscosity.

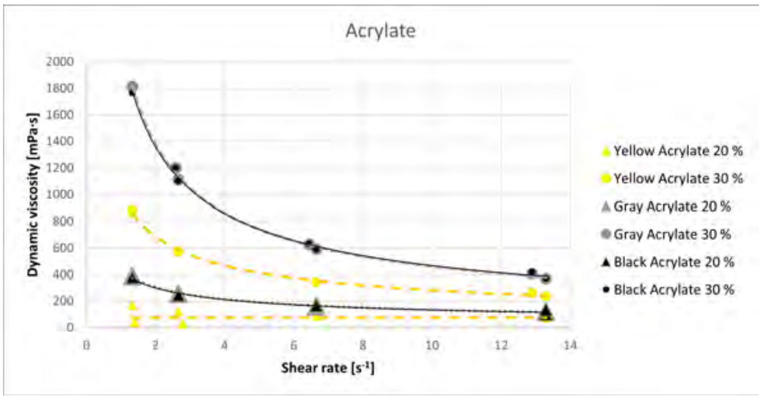
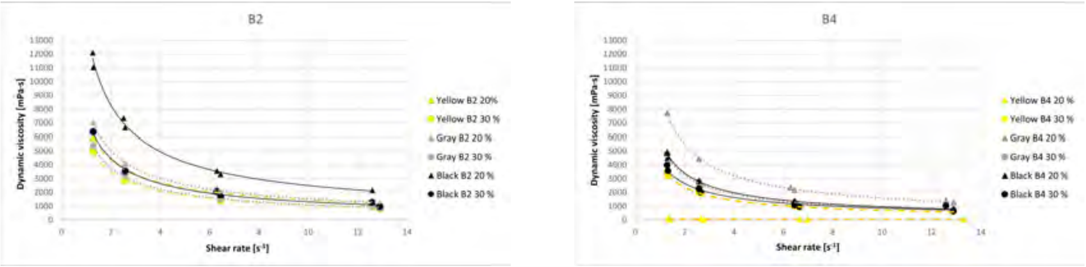


Figure 5.7: Dynamic viscosity for the monobinder paints with acrylate binder. The dots in the graph represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line.

The monobinder paints exhibited very different dynamic viscosity depending on which binder that was used in the paints. In the following graphs, the dynamic viscosity for all monobinder paints with the investigated binders is demonstrated. The monobinder paints with highest viscosity is presented first and thereafter followed by the monobinder paints in decreasing order of viscosity. Note that the scale on the y-axes varies depending on very high or low viscosity´of the paints.

In Figure 5.8, the dynamic viscosity for the paints with binders B2 and B4 can be seen. These paints had the highest viscosity out of all monobinder paints. The paints with binder B2 displayed very high viscosity, where *Black B2 20%* had the highest viscosity, see Figure 5.8a. The paints with binder B4 also exhibited quite high dynamic viscosity, yet lower than the paints with binder B2. The highest viscosity for the B4 monobinder paints was obtained for *Gray B4 20%*.

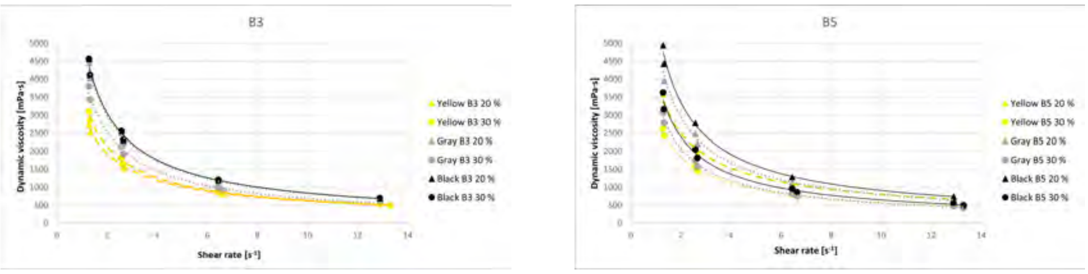


(a) Dynamic viscosity for the monobinder paints with binder B2.

(b) Dynamic viscosity for the monobinder paints with binder B4.

Figure 5.8: Dynamic viscosity for the monobinder paints with binders B2 and B4. The dots in the graphs represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line.

In Figure 5.9, the dynamic viscosity for the paints with binders B3 and B5 can be seen. These paints displayed lower viscosity compared to paints with binders B2 and B4, see Figure 5.8. For the paints with binder B3, *Black B3 30%*, *Black B3 20%* and *Gray B3 20%* displayed the highest viscosity, see Figure 5.9a. These three paints also displayed similar viscosity curves.



(a) Dynamic viscosity for the monobinder paints with binder B3.

(b) Dynamic viscosity for the monobinder paints with binder B5.

Figure 5.9: Dynamic viscosity for the monobinder paints with binders B3 and B5. The dots in the graph represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line.

In Figure 5.10, the dynamic viscosity for the paints with binder B6 can be seen. *Black B6 20%* displayed the highest viscosity followed by *Black B6 30%* and *Gray B6 20%*. The lowest viscosity was obtained for *Gray B6 30%*

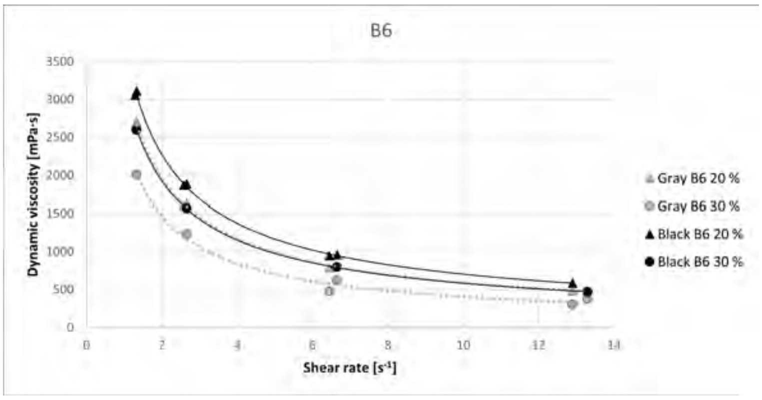


Figure 5.10: Dynamic viscosity for the monobinder paints with binder B6. The dots in the graph represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line.

Lastly, the dynamic viscosity for the paints with binder B1 is presented in Figure 5.11. Among all monobinder paints these were the paints which displayed the lowest viscosity. Comparing the paints with PVC 20% and 30% it can be seen that there is a clear division where the paints with PVC 20% exhibited the lowest viscosity.

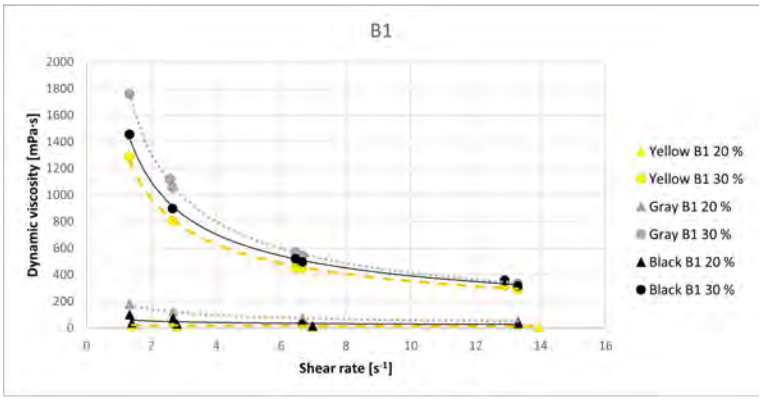


Figure 5.11: Dynamic viscosity for the monobinder paints with binder B1. The dots in the graph represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line.

In summary, the paints with binder B2 displayed the highest viscosity while the paints with binder B1 displayed the lowest. Generally, it could be seen that the yellow paints often exhibited a lower viscosity compared to the gray and black paints. Further, paints with PVC 20% often displayed a higher viscosity compared to paints with PVC 30%. As the pigment volume is constant in all paints, this could be due to the fact that the paints with PVC 20% contained more binder and therefore can be expected to display a higher viscosity. One exception was seen for the paints with B1 where the opposite correlation was seen.

5.1.3 Color Measurement of Wet Paint

In this section, the L-values for the wet paints will be presented. The L-values represent lightness/darkness of the paint, see section 3.4. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

Figure 5.12 demonstrates the L-values for the gray, wet monobinder paints.

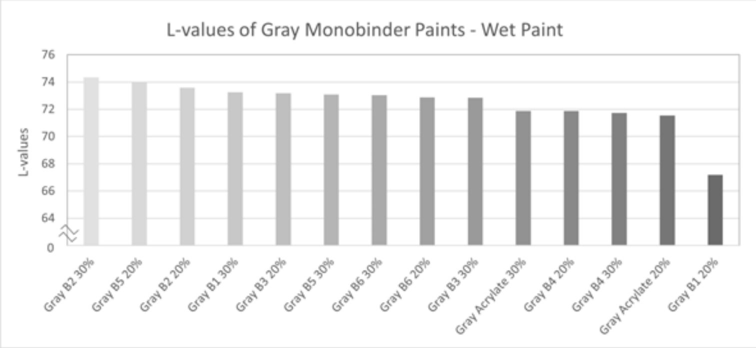


Figure 5.12: L-value for gray, wet monobinder paints. The lightest paints are to the left in the graph and the darkest paints are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

Gray B2 30% had the lightest color with a L-value of 74.34, while monobinder paint *Gray B1 20%* had the darkest with a L-value of 67.17. However, a L-value of 67.17 is still more towards the lighter section of the Hunter "Lab" scale, see Figure 3.3. Moreover, the lightest color was only 7.17 units lighter. Hence, the L-values are very close to each other for the gray paints. Furthermore, there was no obvious correlation between PVC and lightness.

In Figure 5.13, the L-values for the wet, yellow monobinder paints are demonstrated.

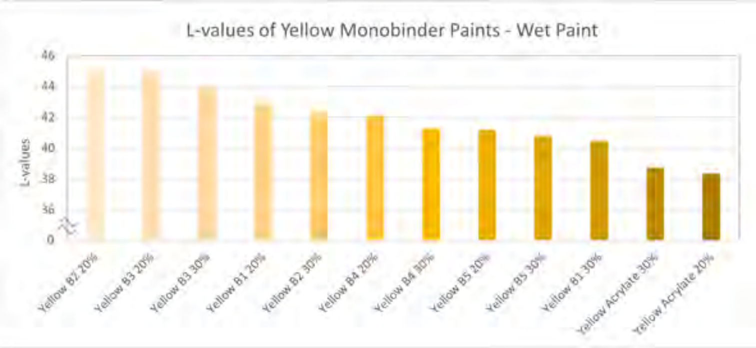


Figure 5.13: L-values for yellow, wet monobinder paints. The lightest paints are to the left in the graph and the darkest paints are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

Yellow B2 20% had the lightest color with a value of 45.22, while monobinder paint *Yellow Acrylate 20%* had the darkest with a value of 38.33. Consequently, the lightest color was only 6.89 units lighter. The monobinder paint with lower PVC was always lighter compared to the monobinder paint with the same binder but with higher PVC. However, this behaviour was not seen for the monobinder paints with acrylate binder where the paints had equal lightness. Furthermore, all yellow wet monobinder paints were below 50 on the Hunter "Lab" scale, see Figure 3.3. Hence, all wet, yellow paints were dark.

In Figure 5.14 are the L-values for the black monobinder paints demonstrated. Monobinder paint *Black B5 30%* had the lightest color with a value of 30.42, and monobinder paint *Black Acrylate 20%* had the darkest with a value of 27.23. Consequently, the lightest color was only 3.19 units lighter. There is no clear pattern of PVC having an effect on lightness. Moreover, all black wet paints were more towards the darker section of the Hunter "Lab" scale, see Figure 3.3.

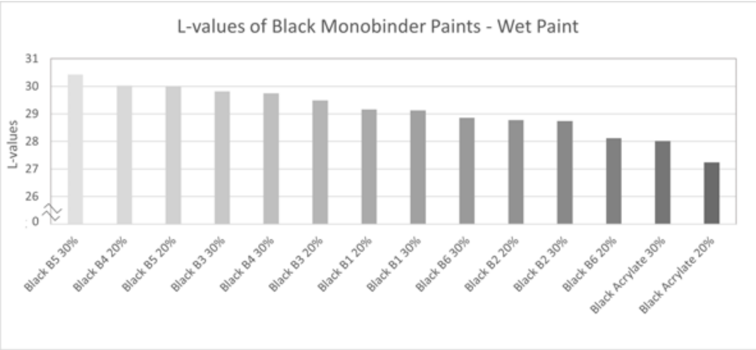


Figure 5.14: L-values for black, wet monobinder paints.The lightest paints are to the left in the graph and the darkest paints are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

To summarize, the L-values for wet monobinder paints with the same color were similar. Furthermore, for both the black and yellow paints, the paints with acrylate binder had lowest L-values. The gray paints with acrylate had low L-values compared to the other gray monobinder paints, but did not exhibit the lowest values. Moreover, only the gray paints were light on the Hunter "Lab" scale. Whereas, yellow and black paints were dark.

5.1.4 Color Measurement of Dry Paint on Boards

In this section, the L-values measured for the the dry monobinder paints on the boards are presented. First, the L-values for the gray monobinder paints are presented. Thereafter, the L-values for the yellow monobinder paints are presented. Lastly, the L-values for the black monobinder paints are presented.

In Figure 5.17, are the L-values for gray monobinder paints as dry paint on the boards presented. *Gray B5 20%* exhibited the lightest color, while *Gray B1 20%* displayed the darkest.

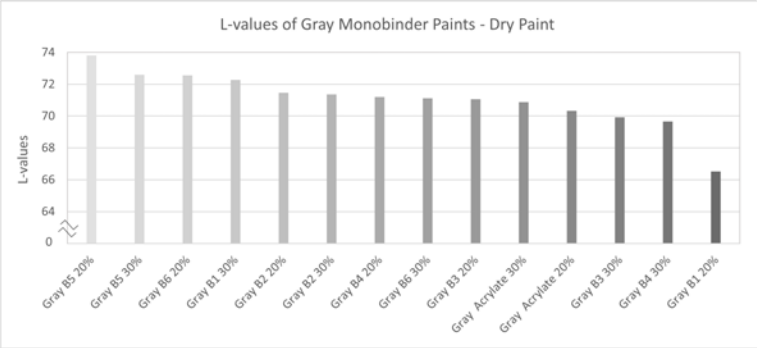


Figure 5.15: L-values for gray monobinder paints as dry paint. The lightest paints are to the left in the graph and the darkest paints are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

In Figure 5.17, are the L-values for yellow monobinder paints as dry paint on the boards demonstrated. *Yellow B3 20%* was the lighest color and *Yellow B2 30%* was the darkest.

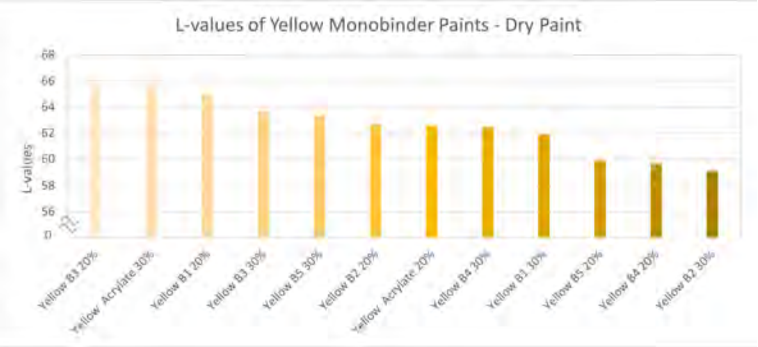


Figure 5.16: L-values for the yellow, wet monobinder paints. The lightest paints are to the left in the graph and the darkest paints are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

Figure 5.17 demonstrates the L-values for black monobinder paints as dry paint on the boards. *Black B2 30%* exhibited the lighest color, while *Black B6 20%* displayed the darkest.

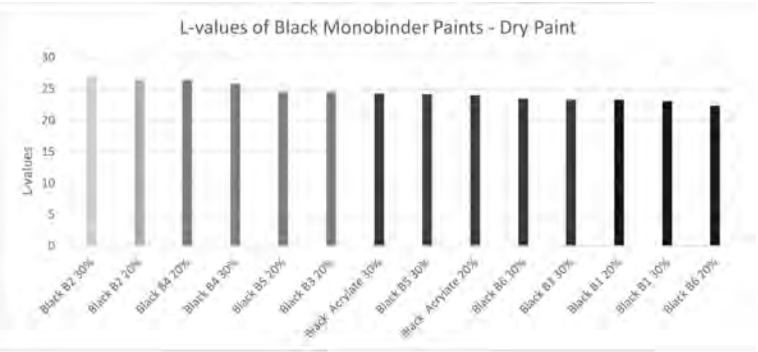


Figure 5.17: L-values for the black, wet monobinder paints. The lightest paints are to the left in the graph and the darkest paints are to the right.

5.1.5 Color Measurement of Dry and Wet Paint

L-values for the gray monobinder paints, both as wet and dry paint, is demonstrated in Figure 5.18. The L-value for every gray monobinder paint decreased when painted and dried on the boards.

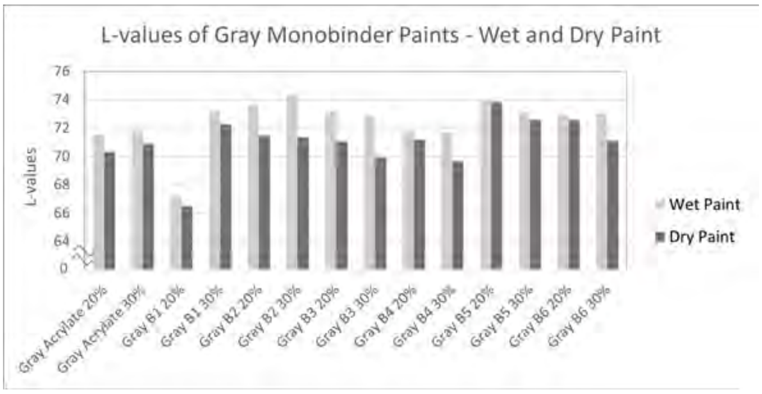


Figure 5.18: L-values for gray monobinder paints for wet and dry paint. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

L-values for the yellow monobinder paints, both as wet and dry paint, is demonstrated in Figure 5.19. The L-value for every yellow monobinder paint increased when painted and dried on the boards, contrary to the gray paints, see Figure 5.18.

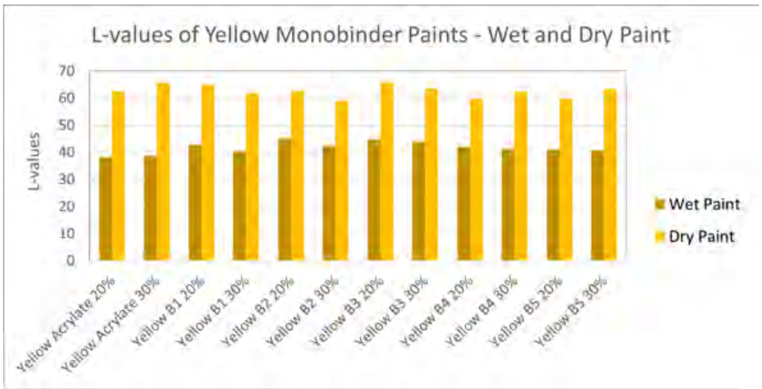


Figure 5.19: L-values for yellow monobinder paints for wet and dry paint.

L-values for the black monobinder paints, both as wet and dry paint, is demonstrated in Figure 5.20. Similarly to the gray paints, the L-value of every black monobinder paint decreased when painted and dried on the boards.

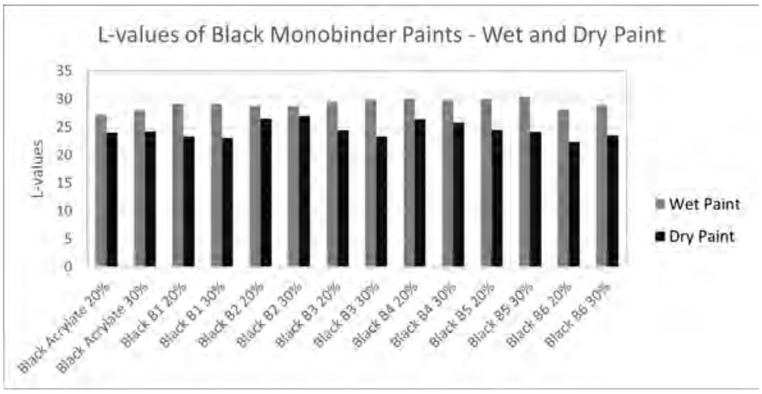


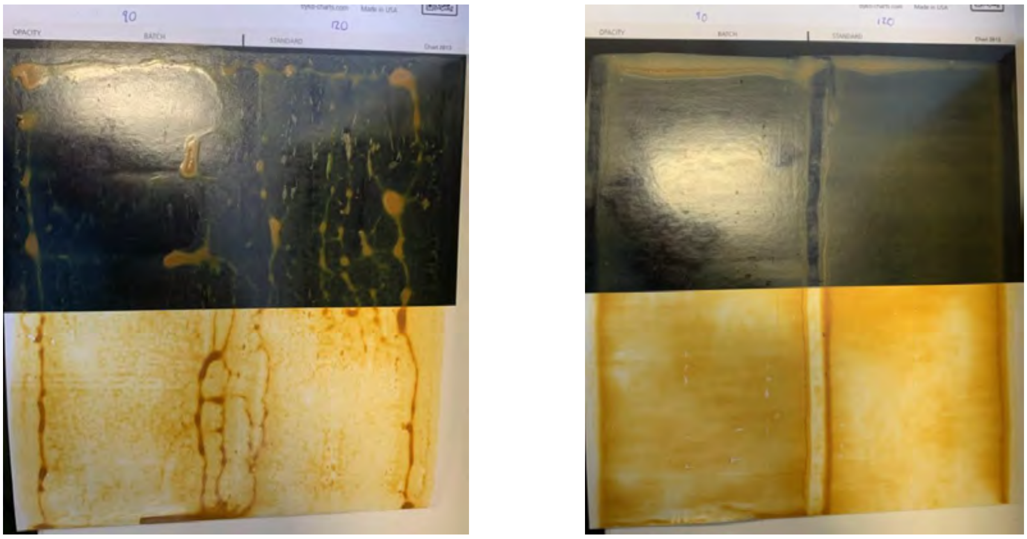
Figure 5.20: L-values of black monobinder paints for wet and dry paint.

To summarize, the yellow monobinder paints increased in lightness when painted and dried on boards and the gray and black paints decreased. The yellow paints went from dark to light values on the Hunter "Lab" scale.

5.1.6 Texture of Paint Coating

In this section, the result will be presented with a few selected figures that will represent a general result for the paints with the same binder. To the left in each figure, a film of 90 μm can be seen and to the right, a film of 120 μm can be seen.

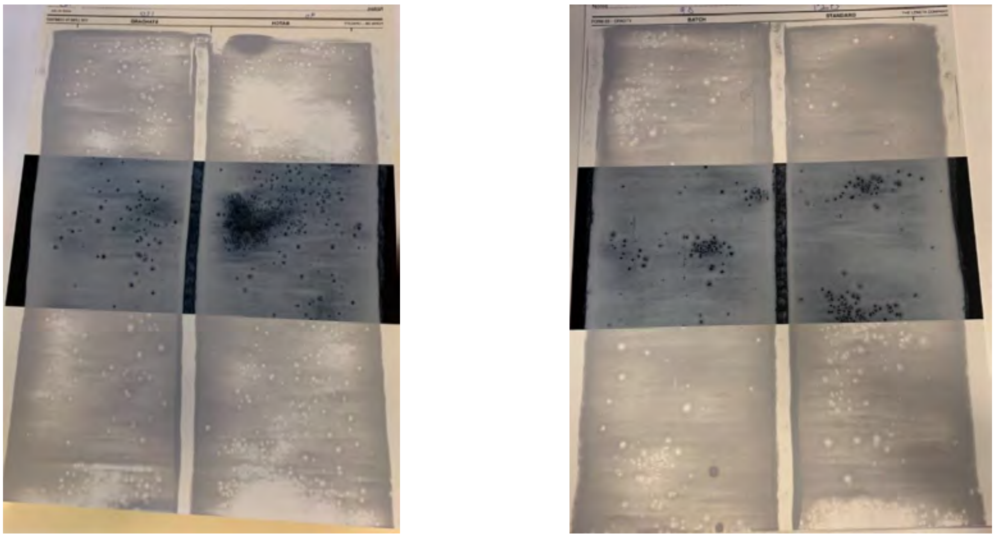
For the monobinder paints with binder B1, a clear distinction between paints with PVC 20% and paints with PVC 30% could be seen. The paints with PVC 20% were more runny and left a characteristic print where thicker lines and spots of coating could be seen, see Figure 5.21a. However, *Gray B1 20%* resulted in a less runny film, the film was more smooth, like the paints with PVC 30%, but the surface was more granular. The binder B1 paints with PVC 30% had a more smooth, homogeneous film than the paints with PVC 20%, see Figure 5.21b.



(a) *Yellow B1 20%* **(b)** *Yellow B1 30%*

Figure 5.21: Coating of Monobinder Paints with binder B1 painted on leneta paper. To the left in each picture the film is 90 μm thick, and to the right the film is 120 μm.

An interesting discovery of the coatings of binder B2 was that the surfaces contained several holes in the film, see Figure 5.22. This was characteristic for all films with binder B2. No visible differences between the paints with PVC 20% and the paints with PVC 30% could be seen.

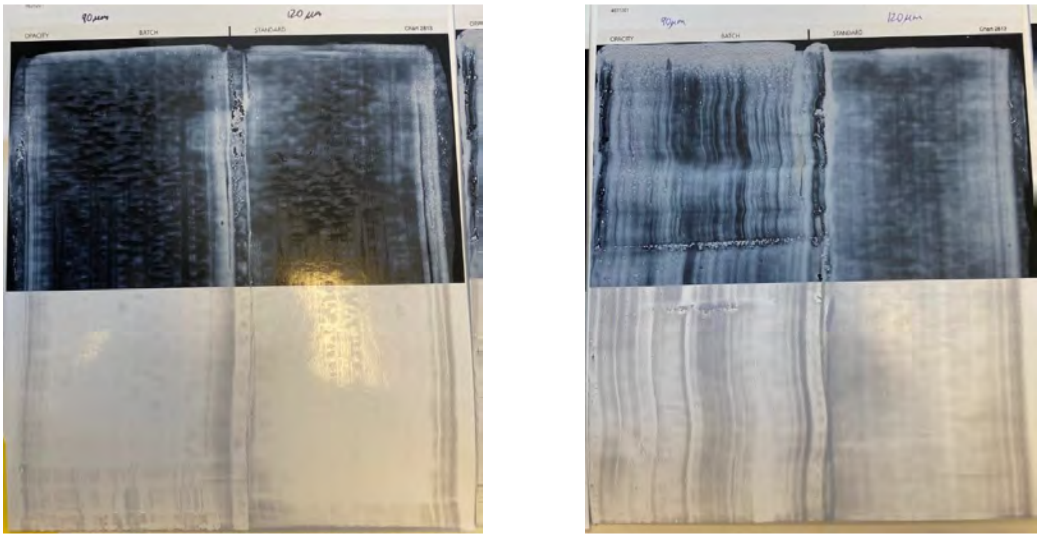


(a) *Gray B2 20%* **(b)** *Gray B2 30%*

Figure 5.22: Coating of monobinder paints with binder B2 painted on leneta paper. To the left in each picture the film is 90 μm thick and to the right the film is 120 μm.

The B3 monobinder paints also contained small holes in the film. Regardless of the small holes, the paints were smooth and similar to the paints with B5 and the paints with acrylate. However, the coating from *Black B3 30%* was different from the other B3 monobinder paints, the paint exhibited larger areas without paint.

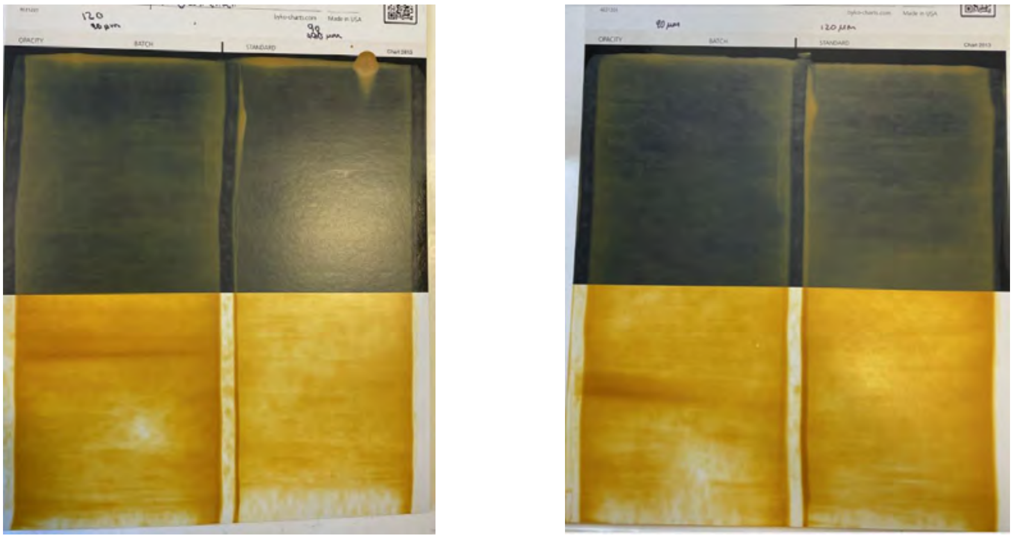
In Figure 5.23, the coatings for *Gray B4 20%* and *Gray B4 30%* are demonstrated. The films contained spots with no paint at all. This trend was spotted in all paint films with binder B4.



(a) *Gray B4 20%* **(b)** *Gray B4 30%*

Figure 5.23: Coating of monobinder paints with binder B4 painted on leneta paper. To the left in each picture the film is 90 μm thick and to the right the film is 120 μm.

Typical for all monobinder paints with binder B5 is that the film is smooth on the leneta paper, see Figure 5.24.



(a) *Yellow B5 20%* **(b)** *Yellow B5 30%*

Figure 5.24: Coating of monobinder paints with binder B5 painted on leneta paper. To the left in each picture the film is 90 μm thick and to the right the film is 120 μm.

A general result for the monobinder paints with acrylate binder is that they are similar to the monobinder paints with binder B5, see Figure 5.25. The film is smooth.

(a) *Black Acrylate 20%* **(b)** *Black Acrylate 30%*

Figure 5.25: Coating of monobinder paints with acrylate binder painted on leneta paper. To the left in each picture the film is 90 μm thick and to the right the film is 120 μm.

The paints with B6 are similar to the paints with binder B5 and to the paints with acrylate. However, the areas with no paint are slightly larger in comparison and the film is not as smooth.

5.1.7 Gloss Measurement on Wood

In this section the gloss measurements on wood are presented.

In Figure 5.26, the reference paints with acrylate can be seen. The color of each bar represents the color of the paint and there are two paints for every color, one has PVC 20% and one has PVC 30%.

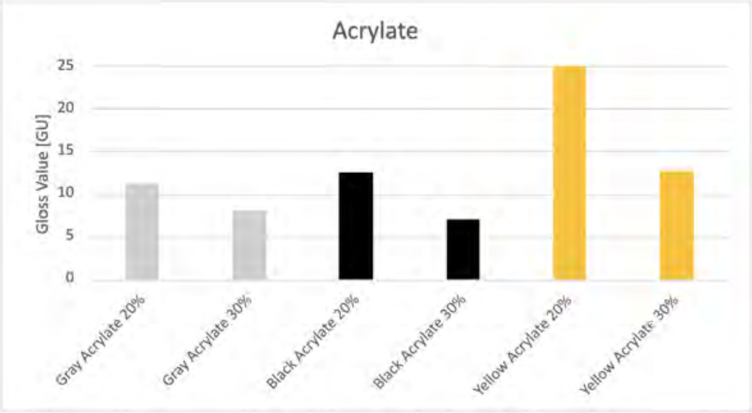
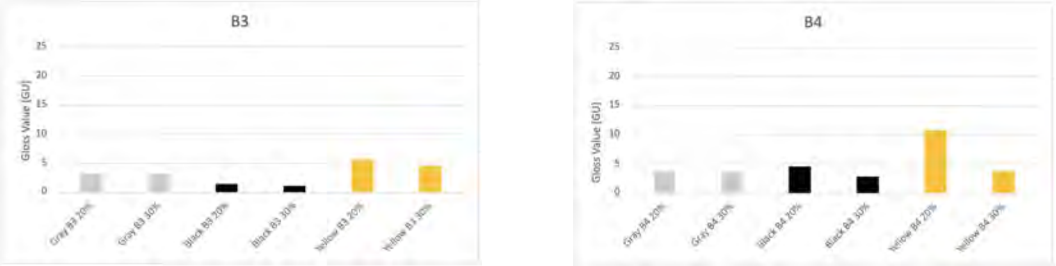


Figure 5.26: Gloss measurements for monobinder paints with acrylate binder.

In Figure 5.27, gloss values for all monobinder paints are presented. In Figure 5.27a, gloss values for the paints with binder B1 is demonstrated. All paints with binder B1 had similar amount of gloss, around 4 GU, and were matter than the paints with acrylate. In Figure 5.27b, gloss values for paints with binder B2 can be seen. The values were also lower than the reference with acrylate and quite similar, around 4 GU. In Figure 5.27c, gloss values for paints with binder B3 can be seen. Similarly, the gloss values were low and close to 3 GU. In Figure 5.27d, gloss values for paints with binder B4 can be seen. The gloss value of *Yellow B4 20%* stood out and had a value of 11 GU. The other paints had gloss values close to 4 GU. However, all paints with binder B4 still had lower gloss values than their counterparts with acrylate binder. In Figure 5.27e, gloss values for paints with binder B5 can be seen. Generally, the B5 monobinder paints exhibited high gloss compared to the other monobinder paints. In Figure 5.27f, gloss values for paints with binder B6 can be seen and for the B6 paints there are only gray and black paints, see 4.1 for an explanation. The gloss values were quite low for the B6 monobinder paints, around 4 GU. However, the black B6 paints had slightly higher gloss than the gray paints.

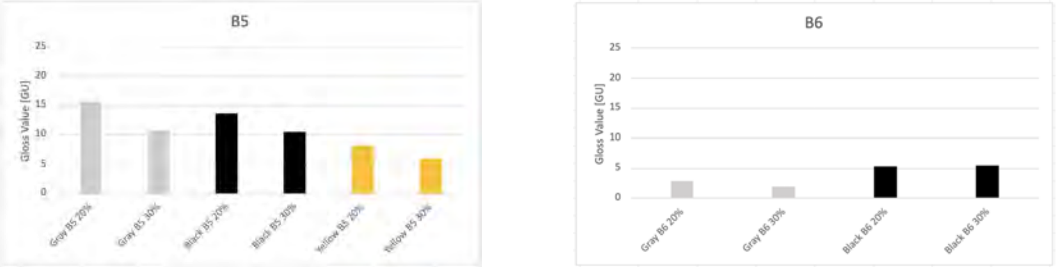
(a) Gloss measurements for monobinder paints with binder B1.

(b) Gloss measurements for monobinder paints with binder B2.



(c) Gloss measurements for monobinder paints with binder B3.

(d) Gloss measurements for monobinder paints with binder B4.



(e) Gloss measurements for monobinder paints with binder B5.

(f) Gloss measurements for monobinder paints with binder B6.

Figure 5.27: Gloss measurements on wood for monobinder paints.

To sum up, the paint *Yellow Acrylate 30%* had the highest gloss value of 25 GU, see Figure 5.26. The paint with the next highest gloss is *Gray B5 20%* with 16 GU, see Figure 5.27e. In fact, almost all paints with a PVC of 20% had higher gloss than the paints with 30% in the same color and with the same binder. Although, there are some exceptions, for the paints with binder B1, the opposite correlation is visible. For the paints with binder B1, the paints with PVC 30% had slightly higher gloss. Noteworthy, is that the black paints with binder B6, the gray paints with binder B1, the gray and black paints with binder B3 and the gray paint of binder B4 had almost the same amount of gloss. Gloss should decrease the closer the PVC is to CPVC so a PVC of 30% could be closer to the paints CPVC, see section 2.3. Gloss can also be affected by the gloss of the substrate.

In Table 5.3, the mean gloss values are demonstrated for all paints with the same type of binder. The mean value is rounded to the nearest integer. The acrylate paints had the highest average mean value of 13 GU. Looking at the binders of investigation, binder B5 paints had the highest mean value of 11 GU, the other binders had values around 3 to 5 GU.

Table 5.3: Gloss mean value for paints with same type of binder on wood boards.

Binder	**Gloss Mean Value [GU]**
B1	4
B2	4
B3	3
B4	5
B5	11
B6	4
Acrylate	13

5.1.8 Gloss Measurement on Leneta

In this section, the gloss measurements on leneta paper is presented. The gloss values were measured on the white part of the leneta paper with a paint film thickness of 120 μm. The Figure 5.28, shows the gloss values for the reference paint with acrylate binder. Equivalently as in the graphs for gloss measurements on wood, the color of each bar represents the color of the paint. For every color there are two paints, one with PVC 20% and one with PVC 30%.

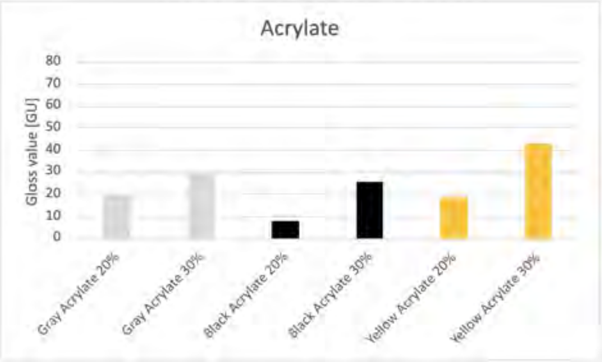
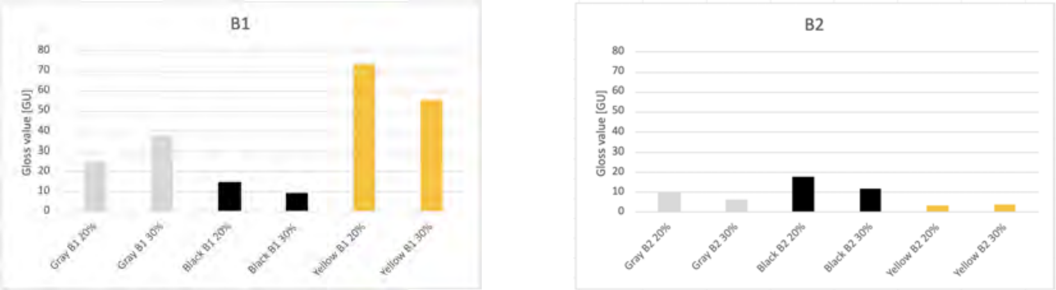


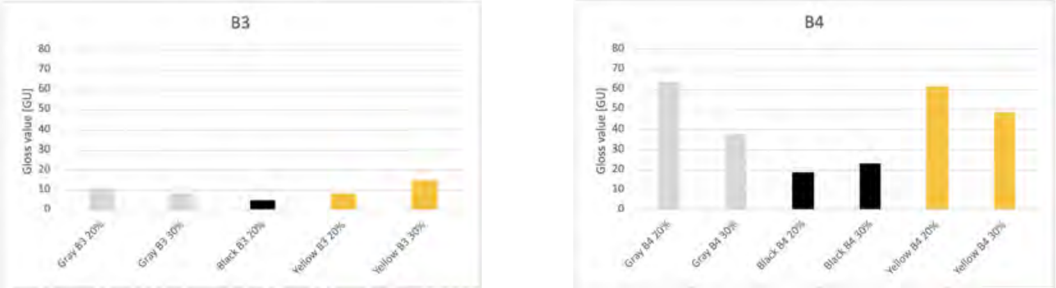
Figure 5.28: Gloss for acrylate binder on leneta paper.

In Figure 5.29, the gloss values on leneta paper can be seen for all monobinder paints. The gloss values for the monobinder paints with B1 can be seen in Figure 5.29a. *Yellow B1 20%* and *Yellow B1 30%* displayed very high gloss values while the gray and black paints showed lower values. Compared to the reference paints with acrylate, the B1 paints exhibit gloss values within in the same range, except for the yellow paints which showed much higher gloss. In Figure 5.29b, the gloss values for the paints with B2 is demonstrated. These paints had quite low gloss values. Compared to the reference paints with acrylate binder, the B2 paints were matter except for *Black B2 20%* which had more gloss than *Black Acrylate 20%*. In Figure 5.29c, the gloss values for the paints with B3 are showed. All the paints with B3 had low gloss, between 5-14 GU. The gloss value for *Black B3 30%* is missing, this was due to that the paint film had several sections where paint was missing and therefore it was not possible to measure gloss. Comparing to the reference paints with acrylate, the B3 paints had lower gloss. One exceptions was *Black B3 20%* which had similar gloss as *Black Acrylate 20%*. In Figure 5.29d, the gloss values for paints with B4 is presented. All paints with B4 had quite high gloss values. Compared to the reference paints with acrylate, all paints with B4 had higher gloss values. Further, in Figure 5.29e the gloss values for paints with B5 can be seen. These paints also had quite high gloss values, and additionally they had higher gloss compared to the reference paints with acrylate. Lastly, in Figure 5.29f the gloss values for paints with B6 are demonstrated. In the graph there are only values presented for black and gray paints, see section 4.1 for the explanation. The black paints had higher gloss compared to the gray paints. Comparing to the reference paints with acrylate binder, the paints with B6 had higher gloss.



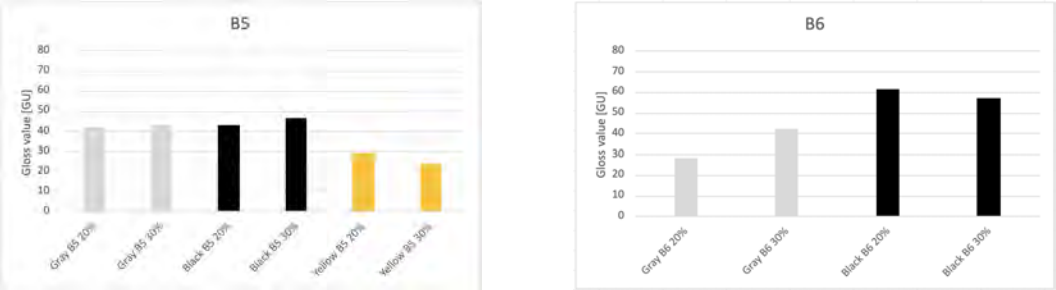
(a) Gloss measurements for monobinder paints with binder B1.

(b) Gloss measurements for monobinder paints with binder B2.



(c) Gloss measurements for monobinder paints with binder B3.

(d) Gloss measurements for monobinder paints with binder B4.



(e) Gloss measurements for monobinder paints with binder B5.

(f) Gloss measurements for monobinder paints with binder B6.

Figure 5.29: Gloss measurements on leneta paper for monobinder paints.

In summary, out of all monobinder paints *Yellow B1 20%* displayed the highest gloss value of 74 GU. The second highest value did *Gray B4 20%* display with a value of 64 GU. When comparing the different binders, it could be seen that the paints with B1, B4, B5 and B6 showed the highest gloss. The paints with B2 and B3 displayed the lowest gloss, where *Yellow B2 20%* had the lowest value of 3 GU. In section 5.1.7, the mean gloss values on wood, for all paints containing the same type of binder is presented, see Table 5.3. This was not performed for the gloss measurements on leneta paper, the values for the paints with the same type of binder differed too much so there was no point in taking a mean value.

5.1.9 Solid content

In Table 5.4, the solid content in all monobinder paints is presented. A general behaviour which could be seen was that paints with PVC 20% had a higher solid content compared to paints with PVC 30%. One exception was for Black B4 20% and Black B4 30% were the opposite behavior was displayed.

Table 5.4: Solid content for monobinder paints.

Paint	**Solid content** [%]	**Paint**	**Solid content** [%]
Gray B1 20%	24	**Black B4 20%**	20
Gray B1 30%	18	**Black B4 30%**	23
Black B1 20%	26	**Yellow B4 20%**	35
Black B1 30%	18	**Yellow B4 30%**	24
Yellow B1 20%	28	**Gray B5 20%**	29
Yellow B1 30%	21	**Gray B5 30%**	20
Gray B2 20%	26	**Black B5 20%**	31
Gray B2 30%	18	**Black B5 30%**	23
Black B2 20%	26	**Yellow B5 20%**	34
Black B2 30%	19	**Yellow B5 30%**	26
Yellow B2 20%	31	**Gray B6 20%**	18
Yellow B2 30%	21	**Gray B6 30%**	15
Gray B3 20%	19	**Black B6 20%**	20
Gray B3 30%	15	**Black B6 30%**	16
Black B3 20%	17	**Gray Acrylate 20%**	28
Black B3 30%	11	**Gray Acrylate 30%**	19
Yellow B3 20%	24	**Black Acrylate 20%**	28
Yellow B3 30%	17	**Black Acrylate 30%**	18
Gray B4 20%	28	**Yellow Acrylate 20%**	32
Gray B4 30%	20	**Yellow Acrylate 30%**	21

5.1.10 Cross Hatch Adhesion Test

The cross hatch adhesion test for the monobinder paints exhibited varying results. In Figure 5.30, the result for *Yellow Acrylate 20%* and *Black B6 30%* can be seen. These two paints displayed very different results. The monobinder paint, *Yellow Acrylate 20%* was classified with a value of 1, meaning good adhesion and *Black B6 30%* was classified with a value of 5, meaning very poor adhesion.

(a) Cross hatch test for Yellow Acrylate 20%

(b) Cross hatch test for Black B6 30%

Figure 5.30: Cross hatch testing on planed Scots Pine for monobinder paints.

In Table 5.5, the classification for the cross adhesion test for all monobinder paints can be seen. The reference paints with acrylate exhibited best result with very good adhesion. The paints with B5 and B6 demonstrated very poor adhesion with a classification of 4 or 5. The paints with B2 displayed quite good adhesion. One exception was for *Black B2 30%* which was classified as a 5.

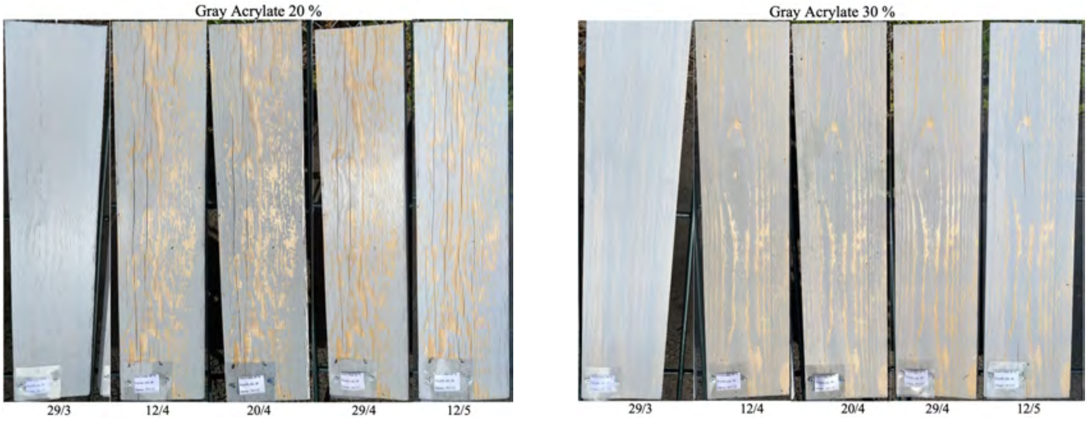
Table 5.5: Classification of monobinder paints for the cross hatch adhesion test. A value of 5 represents poor adhesion and a value of 1 represents good adhesion.

Paint	**Classification**	**Paint**	**Classification**
Gray B1 20%	4	**Black B4 20%**	4
Gray B1 30%	4	**Black B4 30%**	4
Black B1 20%	4	**Yellow B4 20%**	3
Black B1 30%	4	**Yellow B4 30%**	2
Yellow B1 20%	1	**Gray B5 20%**	5
Yellow B1 30%	3	**Gray B5 30%**	5
Gray B2 20%	3	**Black B5 20%**	5
Gray B2 30%	3	**Black B5 30%**	5
Black B2 20%	2	**Yellow B5 20%**	5
Black B2 30%	5	**Yellow B5 30%**	4
Yellow B2 20%	3	**Gray B6 20%**	4
Yellow B2 30%	3	**Gray B6 30%**	5
Gray B3 20%	4	**Black B6 20%**	5
Gray B3 30%	3	**Black B6 30%**	5
Black B3 20%	5	**Gray Acrylate 20%**	1
Black B3 30%	5	**Gray Acrylate 30%**	2
Yellow B3 20%	1	**Black Acrylate 20%**	1
Yellow B3 30%	1	**Black Acrylate 30%**	1
Gray B4 20%	3	**Yellow Acrylate 20%**	1
Gray B4 30%	3	**Yellow Acrylate 30%**	1

5.1.11 Weathering Test

In this section, the result from the weathering test on planed boards is presented. The monobinder paints were made in three different colors (gray, yellow,black), but only the results for the gray monobinder paints were chosen to be displayed. This was due to that the polybinder paints were only produced with a gray color and it would be easier to compare the results for the monobinder- and polybinder paints. However, the weathering test results for the black and yellow paints were taken into consideration when evaluating the result. In this section, the degradation of each gray monobinder paint on the planed boards is displayed. All monobinder paints have been outside for almost seven weeks. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates in all figures are presented in *day/month*.

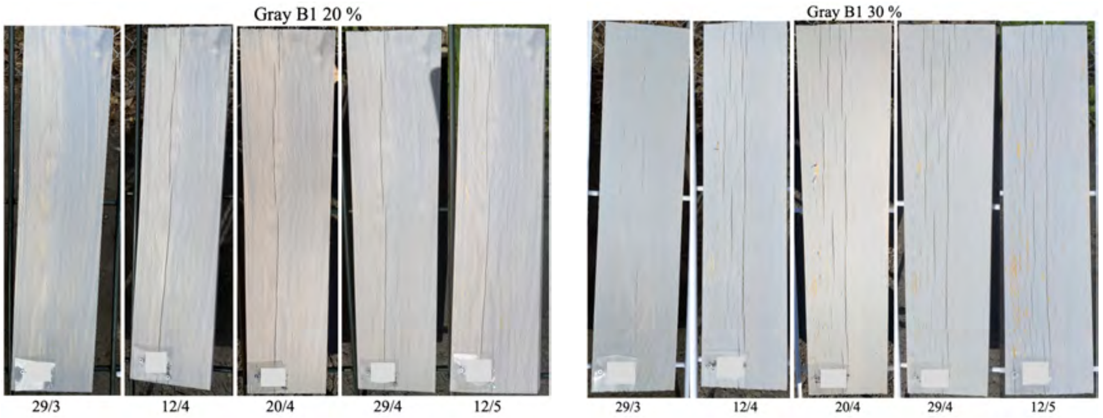
In Figure 5.31, the reference paints with acrylate on planed boards are presented. For *Gray Acrylate 20%*, the paint peeled off quite much after two weeks, see Figure 5.31a. For *Gray Acrylate 30%*, similarly behaviour was seen after two weeks, see Figure 5.31b. For *Gray Acrylate 30%*, there is a pattern where the paint has fallen off, mostly along the latewood growth rings. However, for *Gray Acrylate 20%* the same pattern can not be seen. The paint has fallen off at different spots over the whole board.



(a) *Gray Acrylate 20%* **(b)** *Gray Acrylate 30%*

Figure 5.31: Weathering test for *Gray Acrylate 20%* and *Gray Acrylate 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

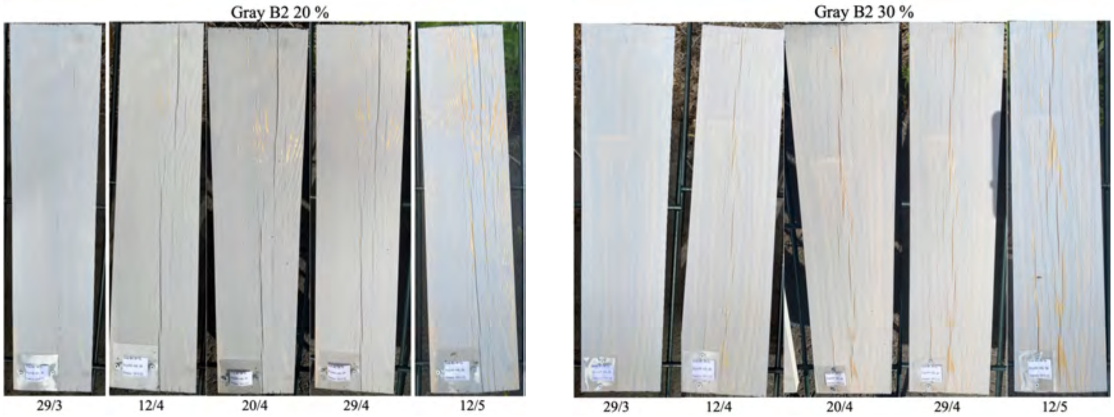
In Figure 5.32, the weathering test on planed boards for *Gray B1 20%* and *Gray B1 30%* can be seen. For both paints the durability of the paints on the boards were good. A lot of the paint is left after seven weeks outside. For *Gray B1 30%*, a few spots can be seen in the bottom left corner were the paint has fallen off more compared to the rest of the board, see Figure 5.32b. In comparison with the reference paints with acrylate, the B1 paints had better durability on the planed boards.



(a) *Gray B1 20%* **(b)** *Gray B1 30%*

Figure 5.32: Weathering test for *Gray B1 20%* and *Gray B1 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

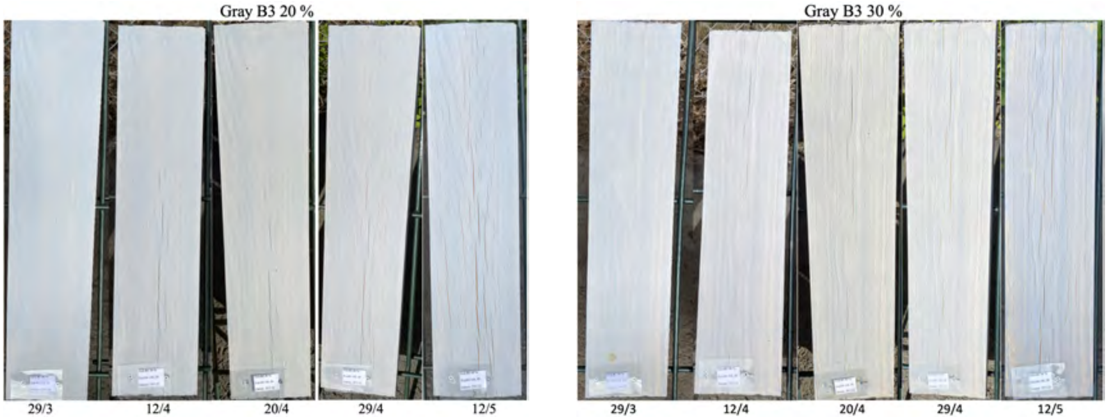
In Figure 5.33, the weathering test for *Gray B2 20%* and *Gray B2 30%* can be seen. Both paints had quite good adhesion on the planed boards, and compared to the reference paint with acrylate both paints displayed better durability. For *Gray B2 20%*, a spot in the top right corner can be seen where the paint has peeled off more compared to paint on the rest of the board. In this spot, growth rings can be seen. A similar appearance can be seen on the board with *Gray B2 30%*, the paint has peeled off at the growth rings where there is latewood, see Figure 5.33b.



(a) *Gray B2 20%* **(b)** *Gray B2 30%*

Figure 5.33: Weathering test for *Gray B2 20%* and *Gray B2 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

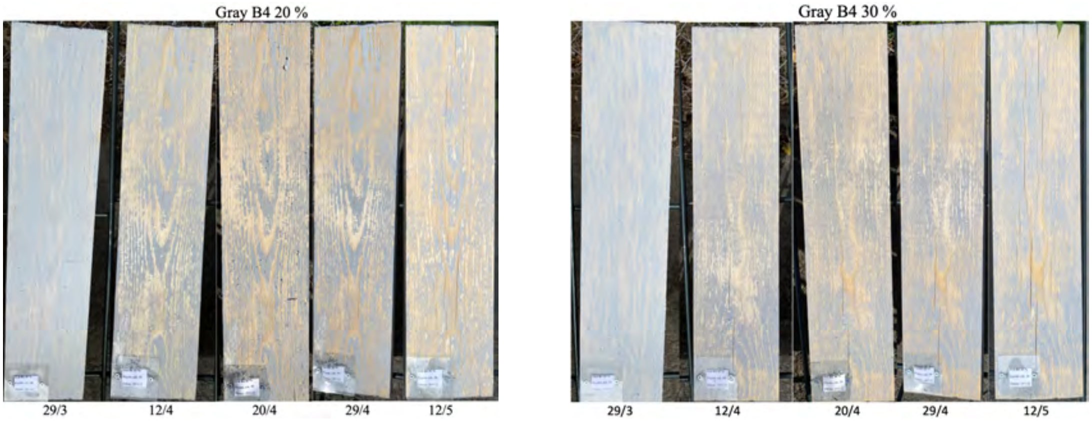
In Figure 5.34, the weathering test for *Gray B3 20%* and *Gray B3 30%* can be seen. Both *Gray B3 20%* and *Gray B3 30%*, exhibited good adhesion and durability of the paint on the planed boards, see Figures 5.34a and 5.34b. Compared to the reference paints with acrylate, the paints with binder B3 displayed better adhesion to the boards. Further, cracks in the boards were observed for both *Gray B3 20%* and *Gray B3 30%*.



(a) *Gray B3 20%* **(b)** *Gray B3 30%*

Figure 5.34: Weathering test for *Gray B3 20%* and *Gray B3 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

In Figure 5.35, the weathering test for *Gray B4 20%* and *Gray B4 30%* can be seen. For *Gray B4 20%*, it can be seen how the paint has clearly peeled off at the growth rings of latewood, see Figure 5.35a. A lot of the paint had fallen off after only two weeks. A similar behaviour can be seen for *Gray B4 30%*, see Figure 5.35a. Compared to the reference paints with acrylate, the paints with binder B4 displayed a similar appearance.

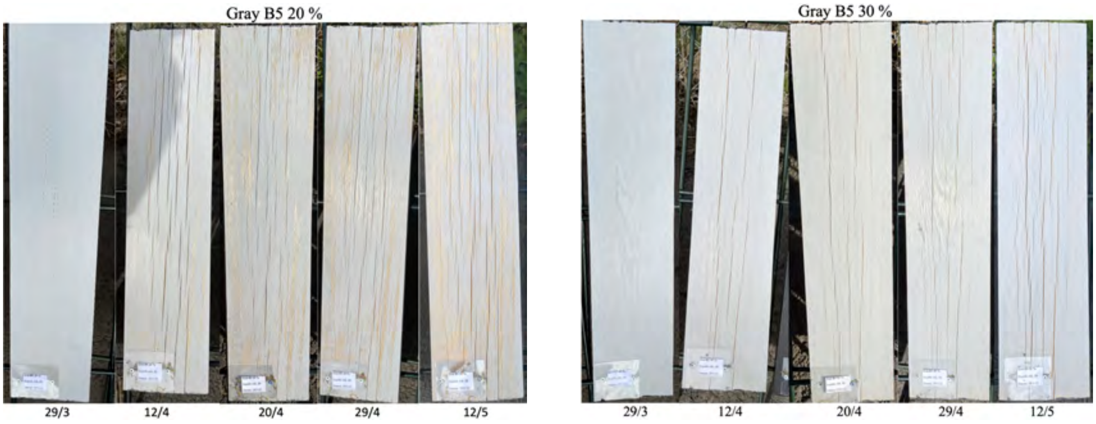


(a) *Gray B4 20%* **(b)** *Gray B4 30%*

Figure 5.35: Weathering test for *Gray B4 20%* and *Gray B4 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

In Figure 5.36, the weathering test for *Gray B5 20%* and *Gray B5 30%* can be seen. Both paints exhibited good adhesion and durability on the boards. However, for *Gray B5 20%* more paint had fallen off compared to *Gray B5 30%*, see Figure 5.36a.

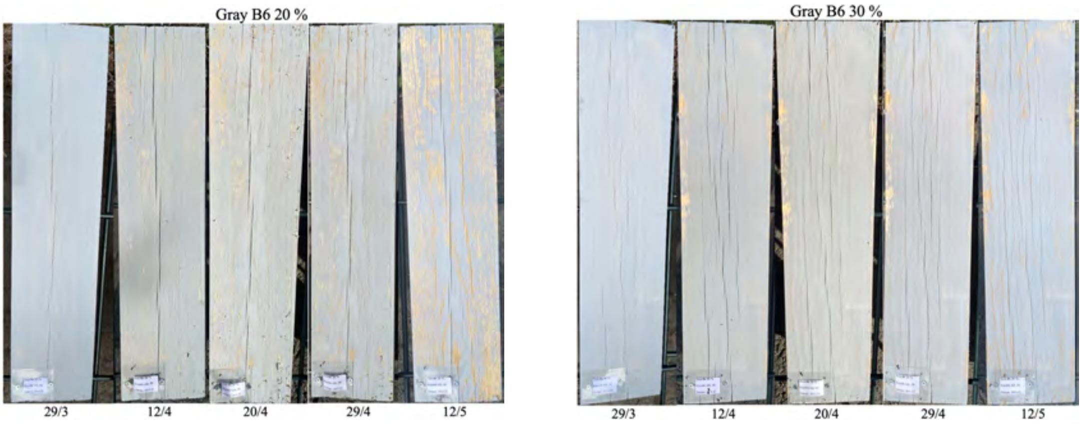
Similarly as for the paints with binder B3, there are visible cracks in the boards for both paints. Further, compared to the reference paints with acrylate, the paints with binder B5 displayed better durability.



(a) *Gray B5 20%* **(b)** *Gray B5 30%*

Figure 5.36: Weathering test for *Gray B5 20%* and *Gray B5 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

In Figure 5.37, the weathering test for *Gray B6 20%* and *Gray B6 30%* can be seen. Both paints exhibited good durability on the planed boards. However, for *Gray B6 20%*, more paint had peeled off compared to *Gray B6 30%*, see Figure 5.37a. In the picture from 20/4 it can be seen that the paint was flaking before falling off. Further, in the picture from 12/5 it can be seen that the paint is starting to peel off at the growth rings of latewood. For *Gray B6 30%*, less paint had peeled off than for *Gray B6 20%*. However, the paint has peeled off at certain spots on the sides of the board, see Figure 5.37b. Compared to the reference paints with acrylate, the paints with binder B6 displayed better durability on the planed boards.



(a) *Gray B6 20%* **(b)** *Gray B6 30%*

Figure 5.37: Weathering test for *Gray B6 20%* and *Gray B6 30%* on planed boards. The starting date for the weathering test was March 29, 2022 and the end date was May, 12, 2022. The dates are presented in *day/month*.

In summary, the weathering test of the monobinder paints displayed varying results. The paints with binder B1 and B3 displayed good durability on the boards. After seven weeks, almost all paint was still left on the planed boards, aside from a few spots where the paint had peeled off. Further, paints with B2, B5 and B6 also displayed good durability on the planed boards. Noteworthy is that the paints with B2 and B6 peeled off at the growth rings of latewood. For B5 this behaviour was not seen, but instead visible cracks could be seen on the boards. For the paints with binder B4 and acrylate, the durability on the boards was poor. For B4 a lot of the paint had peeled off after seven weeks, especially for *Gray B4 20%*, see Figure 5.35a. Also for the paints with acrylate a lot of the paint had peeled off. A general appearance, seen on both the paints with binder B4 and acrylate, was that the paint peeled off at the growth rings of latewood.

5.2 Polybinder Paints

In this section, the result from testing of the polybinder paints is displayed. Hence, testing of paints containing binders B2, B5 and B6 in combination with the acrylate binder and binder Bx is presented. Furthermore, testing of the reference paint, the polybinder paint that solely contain acrylate in combination with Bx, is also presented. Properties that were investigated were storage stability, viscosity, color, texture, gloss, solid content and adhesion durability.

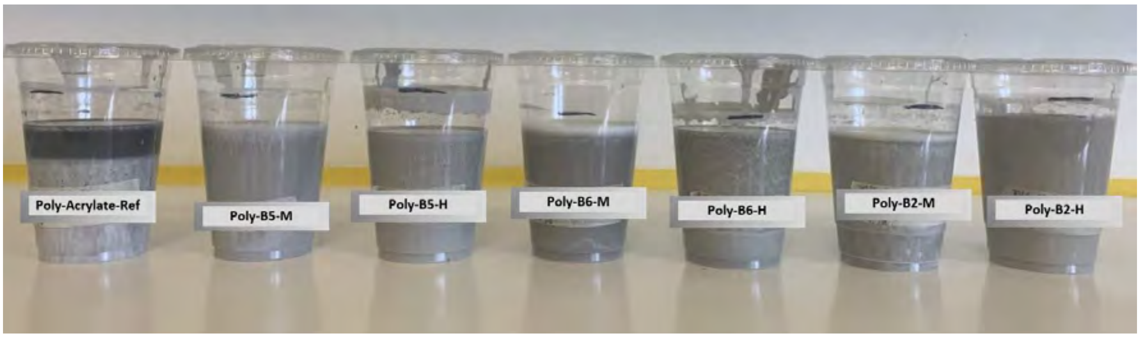
5.2.1 Stability Test

In Table 5.6, the proportion of foam decrease in the stability foam test for the polybinder paints is demonstrated. *Poly-B5-H* was the foamiest paint of the polybinder paints and had a foam decrease of 27%. Thereafter, comes the reference paint, *Poly-Acrylate-Ref* with a decrease of 22%. *Poly-B6-M* was the paint with the lowest foam decrease.

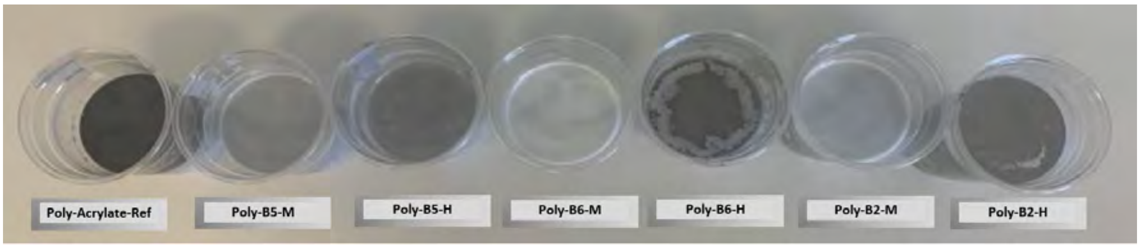
Table 5.6: The proportion of foam decrease in the stability foam tests for polybinder paints.

Paint	**Foam Decrease [%]**
Poly-Acrylate-Ref	22.73
Poly-B5-M	19.05
Poly-B5-H	27.27
Poly-B2-M	19.05
Poly-B2-H	9.09
Poly-B6-M	8.42
Poly-B6-H	15.79

Figure 5.38 demonstrates the result from the stability test of the polybinder paints. For the polybinder paints, the stability test and foam stability test were the same. The stability test had been stored without interference for ca 44 days.



(a) Stability tests for the polybinder paints.



(b) Top surface appearance of the polybinder paints in the stability tests.

Figure 5.38: Stability tests for the polybinder paints. The tests had been stored for 44 days. The foam stability tests and stability tests were the same for the polybinder paints, the manufacture date of the paints was therefore also 44 days ago. a.) All seven stability tests of polybinder paints. Different degrees of pigment separation can be observed. The acrylate reference paint is the one furthest to the left and the others include the investigated binders; B2, B5 and B6, with middle high concentration (M) and high concentration (H). b.) The top surface appearance of the stability tests for the polybinder paints.

The stability test for the reference paint with acrylate binder, *Poly-Acrylate-Ref*, had separated the most. A thick layer of dark pigment could be seen at the surface, see Figure 5.38a. In the bulk, below the dark top layer, there were dark dots in the gray paint. Next, the stability test of *Poly-B5-M* had a homogeneous bulk color. However, contrary to the stability test of *Poly-Acrylate-Ref*, a lightly colored layer had separated to the surface. Similarly, *Poly-B5-H* had a quite homogeneous color but had some air bubbles in the bulk. However, this could be a consequence of using the same test for both foam test and stability test. Furthermore, *Poly-B5-H* had not phase separated. However, *Poly-B6-M* had phase separated, a thin layer of light pigment could be observed at the surface. Likewise, the stability test of *Poly-B6-H* had phase separated but in this case the surface layer was transparent and there was a gray circle on top of the transparent layer. Apart from the phase separation, the bulk of the paint during the stability test was homogeneous. Furthermore, the stability test of *Poly-B2-M* had a heterogeneous color in the bulk because there was a lot of white, small dots in the gray paint. Hence, the overall appearance was hazy.

Furthermore, the sample had phase separated and there was a light colored layer at the surface. *Poly-B2-H*, on the other hand, had a general homogeneous color, more homogeneous color than *Poly-B5-H*, and had not phase separated.

To summarize, stability test of *Poly-B2-H* was the paint that had the most homogeneous color and one of the two paints which had not phase separated. The other paint without phase separation was *Poly-B5-H*. Furthermore, stability test of *Poly-Acrylate-Ref* was the paint which had separated the most. Noteworthy is that all stability tests containing acrylate had phase separated (all tests marked with *M*). However, it was only in *Poly-Acrylate-Ref* where a dark layer could be seen at the surface. In the other paints containing acrylate, a light layer was observed on the surface. Furthermore, *Poly-B6-H* was the only stability test without acrylate which had phase separated (all tests marked with *H*). Although, for *Poly-B6-H*, the surface layer was transparent with some gray pigment.

5.2.2 Viscosity

In Figure 5.39, the viscosity measurements for the polybinder paints can be observed. The paints containing the same investigated binder have the same color on the curves. Similarly as the monobinder paints, the polybinder paints are shear thinning. The figure also demonstrates that polybinder paints with medium content of the investigated binder had lower dynamic viscosity compared to the polybinder paints with high content of the investigated binder. *Poly-B2-H* displayed the highest dynamic viscosity while *Poly-B6-M* displayed the lowest. Notable is that binder B2 also showed highest dynamic viscosity in the monobinder paints, see Table 5.8a. The reference polybinder paint with acrylate, *Poly-Acrylate-Ref*, had the lowest viscosity out of all polybinder paints.

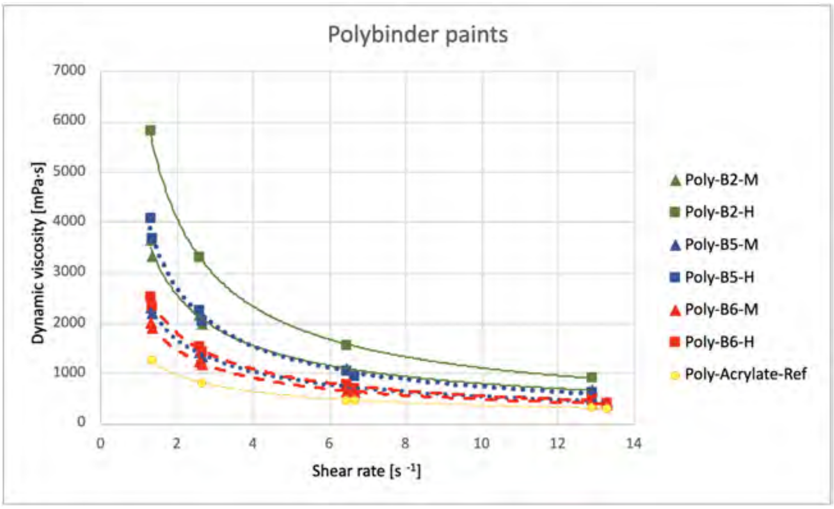


Figure 5.39: Dynamic viscosity of polybinder paints measured for different shear rates. Paints with the same binder has the same color on the curves.The dots in the graph represent the dynamic viscosity measured at different shear rates. The dots are connected with a trend line

5.2.3 Color Measurement for Wet Paint

In Figure 5.40, the L-values for the wet polybinder paints are demonstrated. Polybinder paint, *Poly-B4-H* had the lightest color with a value of 74.40 and polybinder paint, *Poly-B6-M* had the darkest color with a value of 71.64. Consequently, the lightest color was only 2.76 units lighter. *Poly-Acrylate-Ref* was the next darkest paint after *Poly-B6-M*. In relation to that, every paint containing acrylate (marked with *M*) was darker than the paint with the same binder but without acrylate (marked with *H*). Note that the difference in lightness is very small.

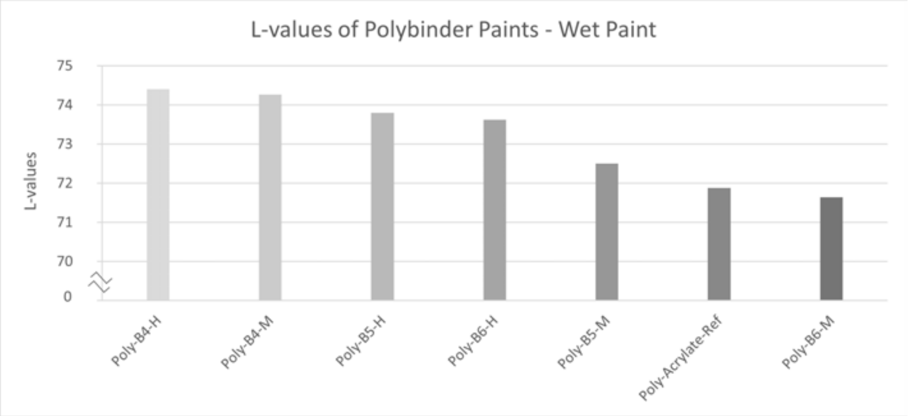


Figure 5.40: L-values for the wet polybinder paints. The paints with the lightest colors are to the left in the graph and the darkest are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

5.2.4 Color Measurement of Dry Paint

In Figure 5.41, the L-values for the dry polybinder paints are demonstrated. *Poly-B6-H* had the lightest color of all polybinder paints whereas, the reference paint, *Poly-Acrylate-Ref* had the darkest color. Note that the difference in lightness is very small.

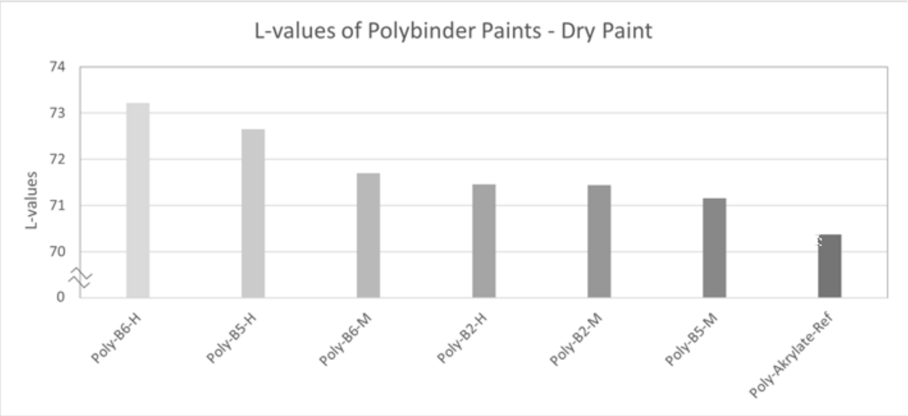


Figure 5.41: L-values of dry polybinder paints. The paints with the lightest colors are to the left in the graph and the darkest are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

5.2.5 Color Measurement of Dry and Wet Paint

L-values for the polybinder paints, both as wet and dry paint, are demonstrated in Figure 5.42. The polybinder paints with binder B2 had changed the most in lightness when painted and dried on boards. However, only by a value of approximately three units. Whereas, *Poly-B6-M* had changed the least in lightness and had basically the same lightness from wet paint to dry paint on boards.

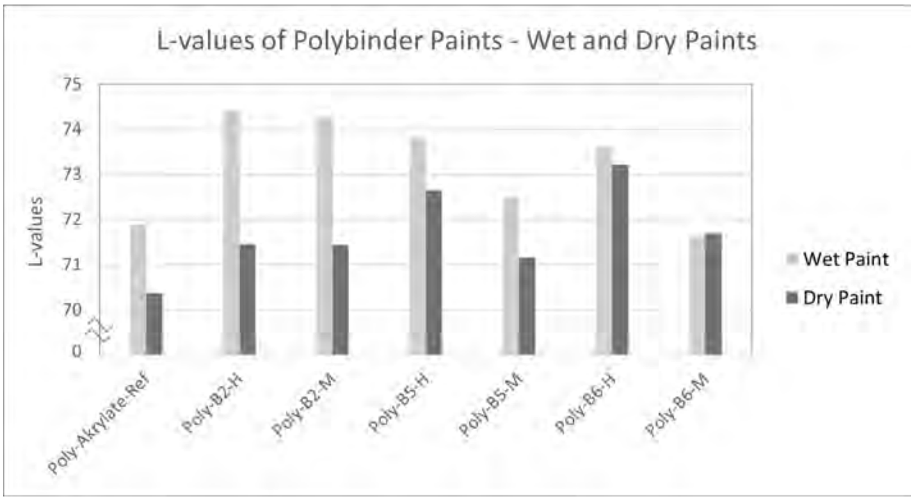
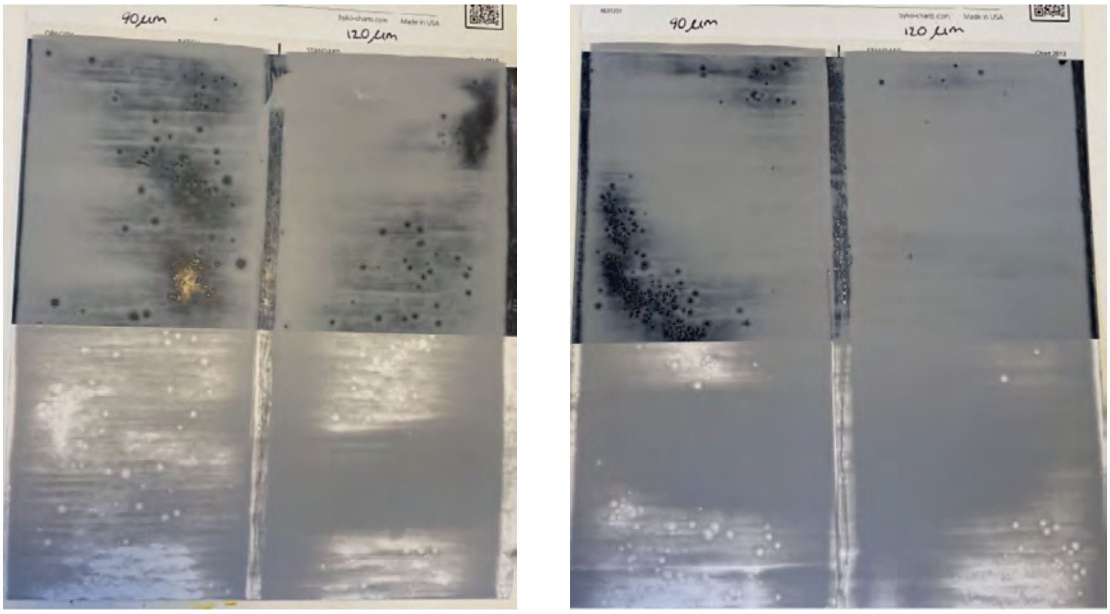


Figure 5.42: L-values for the polybinder paints, both as wet and dry paints. The paints with the lightest colors are to the left in the graph and the darkest are to the right. Note, the broken y-axis, the axis is adjusted to display the difference in L-values more clearly.

5.2.6 Texture of Paint Coating

In this section the result from application of coating on leneta paper will be shown for the polybinder paints. To the left in each picture, a film of 90 μm can bee seen and to the right, a film of 120 μm can be seen. The picture to the left is always the paint containing acrylate, named *M*, and the picture to the right is always the paint without acrylate, named *H*.

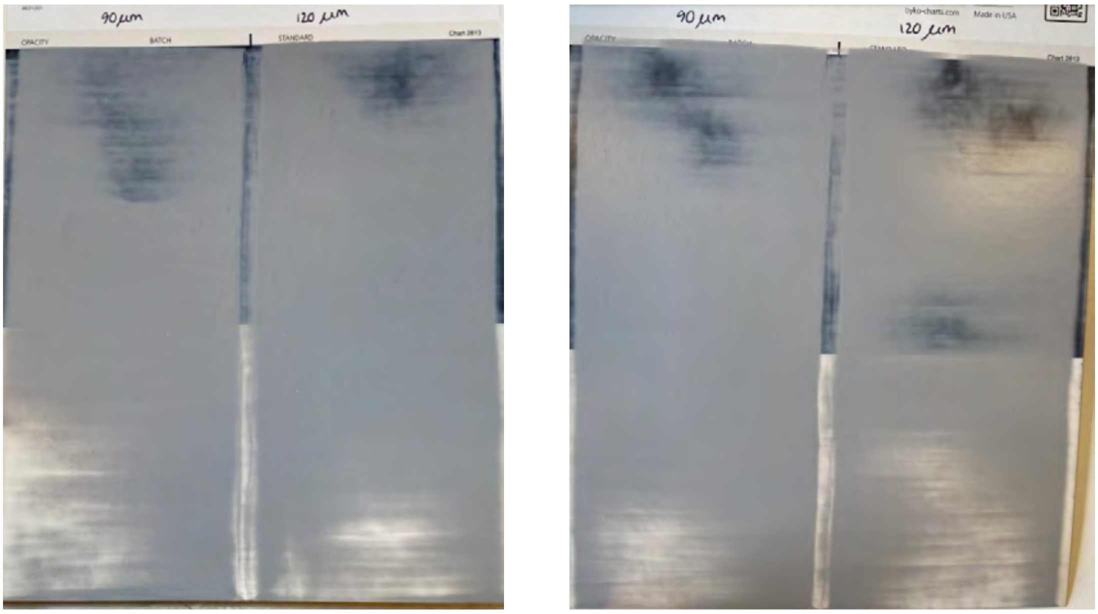
In Figure 5.43, the paint coatings from *Poly-B2-M* and *Poly-B2-H* can be seen on leneta paper. Notable is that these paints also contain small, circular surface defects like the monobinder paints with binder B2, see Figure 5.22



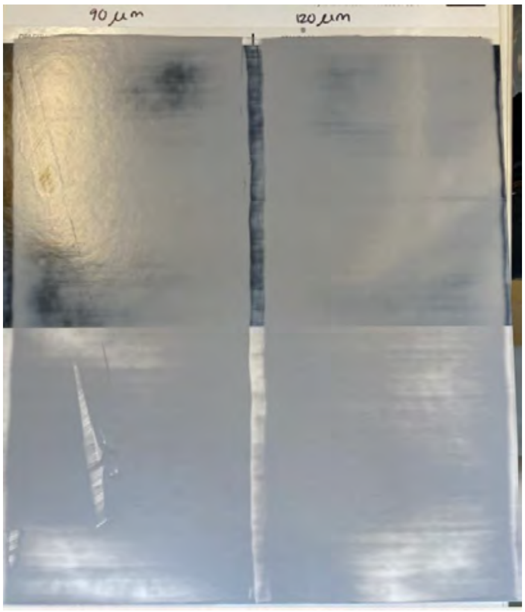
(a) *Poly-B2-M* **(b)** *Poly-B2-H*

Figure 5.43: Coating of polybinder paints containing binder B2 painted on leneta paper. To the left in each picture the film is 90 μm thick and to the right the film is 120 μm.

The reference polybinder paint with acrylate, *Poly-Acrylate-Ref*, and the polybinder paints with binder B5 were similar in appearance on leneta paper, see Figure 5.44. The films had a homogeneous color but contained some areas without paint. However, for *Poly-B5-H* the areas without paint were larger compared to *Poly-B5-M* and *Poly-Acrylate-Ref*.



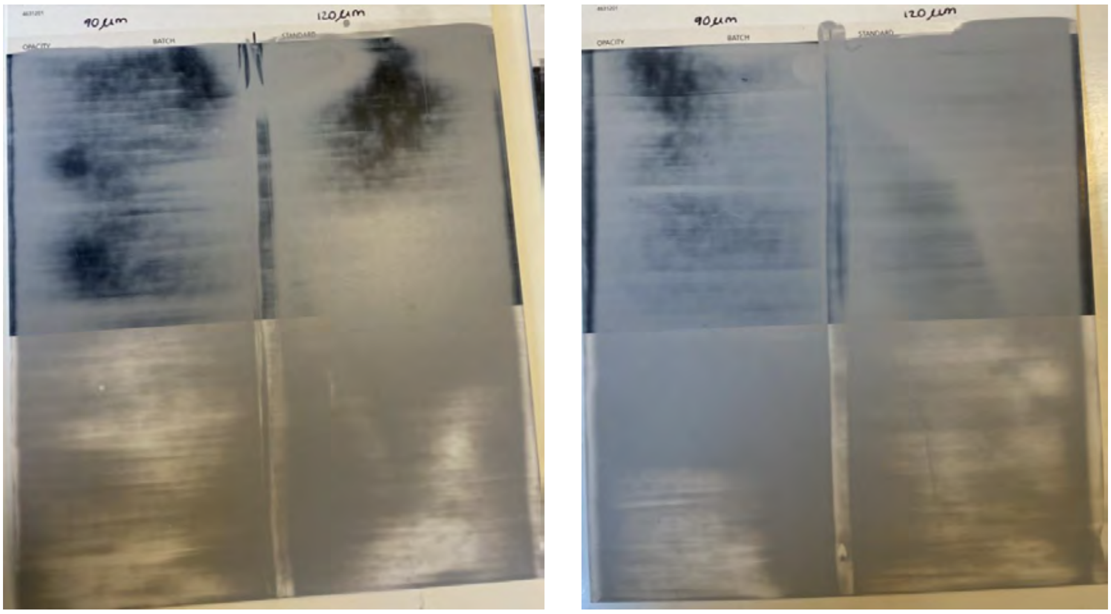
(a) *Poly-Acrylate-Ref* **(b)** *Poly-B5-M*



(c) *Poly-B5-H*

Figure 5.44: Coating of polybinder paints with solely acrylate or with binder B5, applied on leneta paper. To the left in each figure the film is 90 μm thick and to the right the film is 120 μm.

The polybinder paints with binder B6 had larger holes in the film than the B5 polybinder paints and the reference with acrylate, see Figure 5.45. Apart from that, the paints were similar in appearance.



(a) *Poly-B6-M* **(b)** *Poly-B6-H*

Figure 5.45: Coating of polybinder paints containing binder B6, applied on leneta paper. To the left in each picture the film is 90 μm thick and to the right the film is 120 μm.

5.2.7 Gloss Measurement on Wood

Figure 5.26 demonstrates measured gloss values from the polybinder paints applied on the boards. *Gray-B5-M* had the highest gloss of 10 GU and *Gray-B6-H* had the lowest gloss with 3 GU. A possible correlation can be seen where the paints with acrylate have higher gloss than the paint with the same binder without acrylate, for example *Poly-B2-M* have higher gloss than *Poly-B2-H*. This is expected because the monobinder paints with acrylate had high gloss compared to the other binders, see Table 5.3. Furthermore, the polybinder paints with binder B5 had higher gloss than the reference paint *Gray-Acrylate-Ref*, while the polybinder paints with binders B2 and B6 had less gloss than the reference paint. This result is also to be excepted since the monobinder paints with binder B5 had a higher mean gloss value than the monobinder paints with binder B2 or B6, see Table 5.3. Note, the mean gloss values of monobinder paints with acrylate are higher compared to the monobinder paints with binder B5.

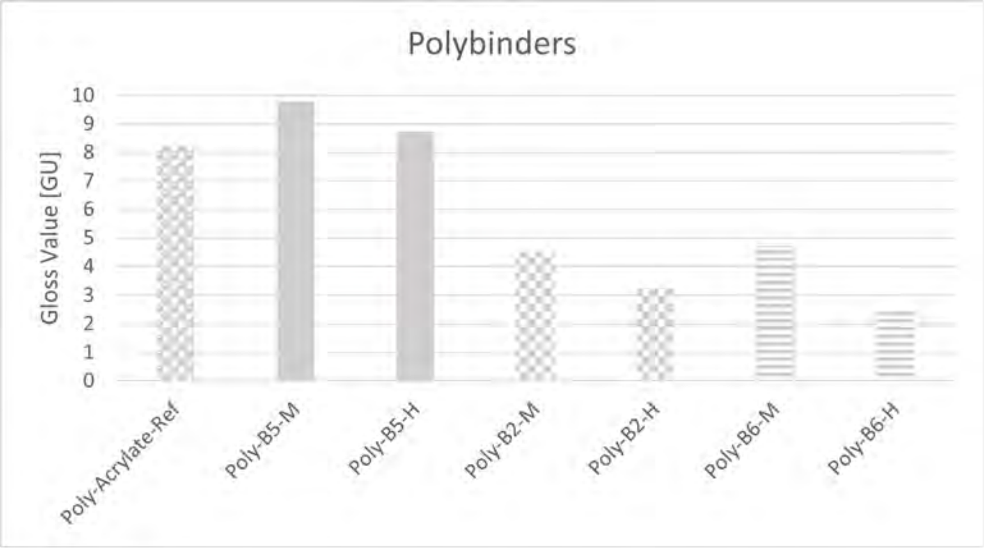


Figure 5.46: Gloss for polybinder paints on wood.

5.2.8 Gloss Measurement on Leneta

In Figure 5.47, the gloss values of the polybinder paints on leneta paper are presented. *Poly-B5-M* displayed the highest gloss value of 35 GU, while *Poly-B2-H* showed the lowest value of 7.7 GU. The reference paint *Poly-Acrylate-Ref*, had quite high gloss, only *Poly-B5-H* and *Poly-B5-M* displayed higher gloss. One general behavior, which could be observed for all polybinder paints, was that the polybinder paints with acrylate (named *M*) demonstrated higher gloss compared to the same polybinder paints but without acrylate (named *H*), for example *Poly-B5-M* had higher gloss than *Poly-B5-H*.

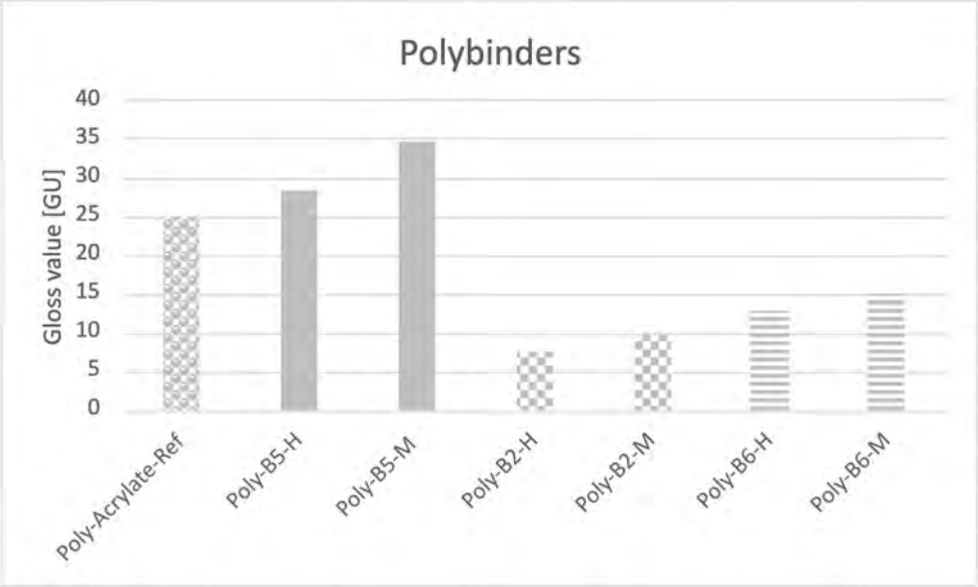


Figure 5.47: Gloss for polybinder paints on leneta paper.

5.2.9 Solid Content

In Table 5.7, the solid contents for all polybinder paints are presented. A general behaviour for all polybinder paints was that the polybinder paints containing acrylate obtained a lower solid content. *Poly-B5-H* had the highest solid content at 24% while *Poly-B6-H* had the lowest solid content at 15%.

Table 5.7: Solid content for polybinder paints.

Paint	**Solid Content [%]**
Poly-Acrylate-Ref	23
Poly-B5-M	22
Poly-B5-H	24
Poly-B2-M	23
Poly-B2-H	21
Poly-B6-M	20
Poly-B6-H	15

5.2.10 Cross Hatch Adhesion Test

In Table 5.8, the classification for the cross adhesion test for all polybinder paints can be seen. The reference paint, *Poly-Acrylate-Ref*, exhibited the best result with a classification of 1. *Poly-B5-H* and *Poly-B2-H* displayed the worst adhesion with a classification of 5. Generally, the polybinder paints containing the acrylate binder had better adhesion to the substrate compared to the ones without acrylate.

Table 5.8: Classification of polybinder paints for the cross hatch adhesion test. A value of 5 represents poor adhesion and a value of 1 represents good adhesion.

Paint	**Classification**
Poly-Acrylate-Ref	1
Poly-B5-M	4
Poly-B5-H	5
Poly-B2-M	2
Poly-B2-H	5
Poly-B6-M	2
Poly-B6-H	4

5.2.11 Weathering Test

In this section, the results from the weathering test on planed boards are presented. For each polybinder paints, five pictures of the development from outdoor testing is displayed. The first picture to the left in every figure demonstrates the coating on the first day of the outdoor testing. All polybinder paints have been outside for slightly more than a month. The starting date for the weathering test was April 5, 2022 and the end date was May 12, 2022. The dates in all figures are presented in *day/month*. The weathering test for the polybinder paints gave varying results. In Figure 5.48, the weathering test on planed boards for *Poly-Acrylate-Ref* can be seen. *Poly-Acrylate-Ref* is the reference paint and, as can be seen in the figure, the paint peeled off quite fast and mostly on the parts with earlywood.

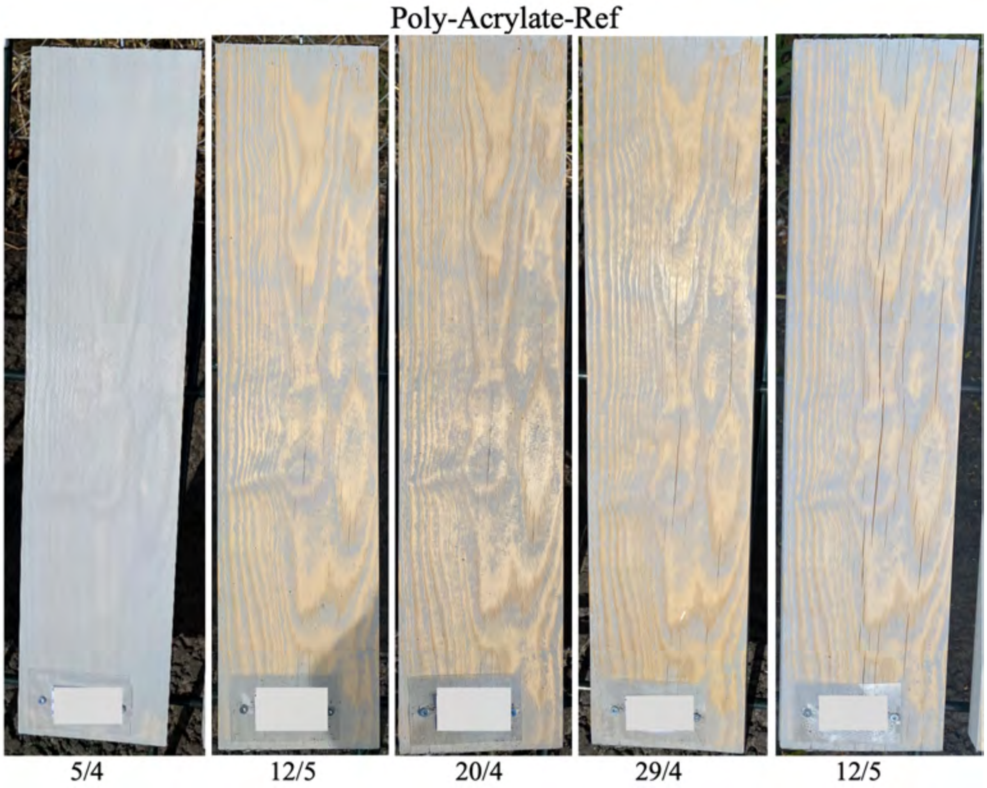


Figure 5.48: Weathering test for *Poly-Acrylate-Ref* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month* in the figure.

In the following four figures, the paints which exhibited the best result during the weathering testing are presented, see Figures 5.49, 5.50, 5.51 and 5.52. In Figure 5.49, the weathering test on planed boards for *Poly-B6-M* can be seen. *Poly-B6-M* exhibited a quite good durability during the weathering testing. The paint had peeled off on the earlywood but compared to the reference paint, it had better durability on the planed boards.

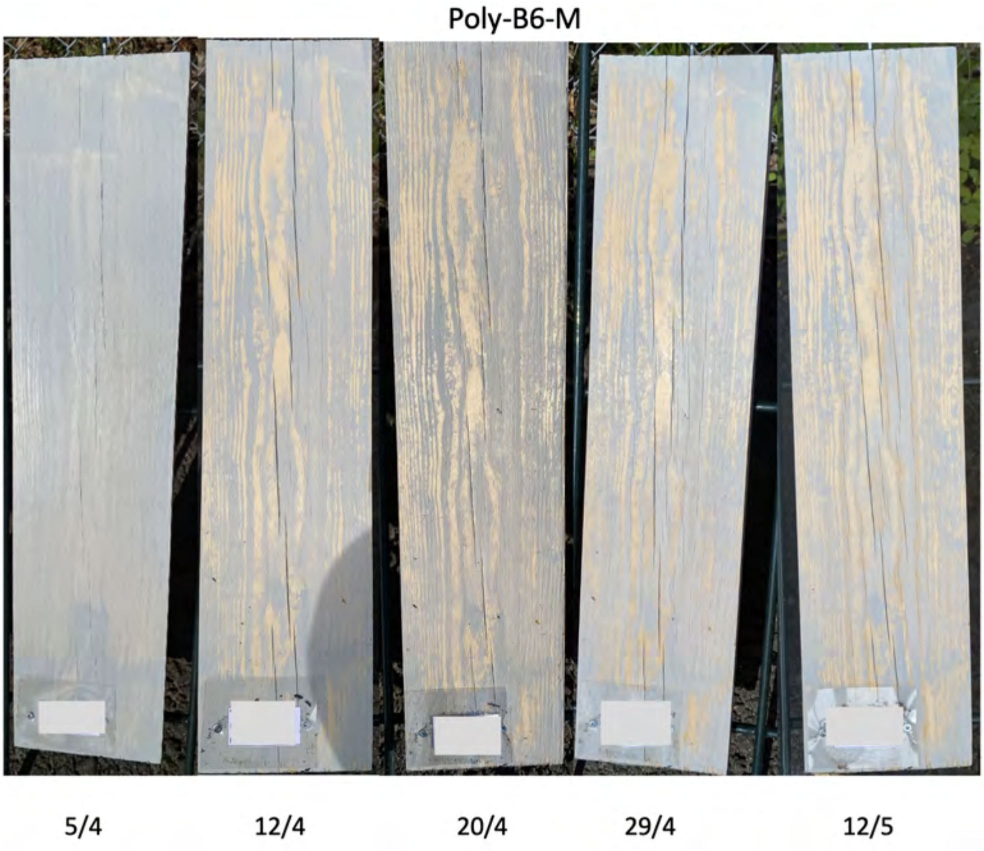


Figure 5.49: Weathering test for *Poly-B6-M* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month* in the figure..

In Figure 5.50, the weathering test on planed boards for *Poly-B6-H* can be seen. The paint had mainly peeled off at the right part of the board. In the picture from 20/4, it can be seen that the paint was flaking before the paint fell off. Compared to *Poly-B6-M*, the paint had peeled off unevenly on the board. It can also be seen that the paint had peeled off at the latewood. Similary as *Poly-B6-M*, the paint had better durability on the planed boards compared to the reference paint *Poly-Acrylate-Ref*.

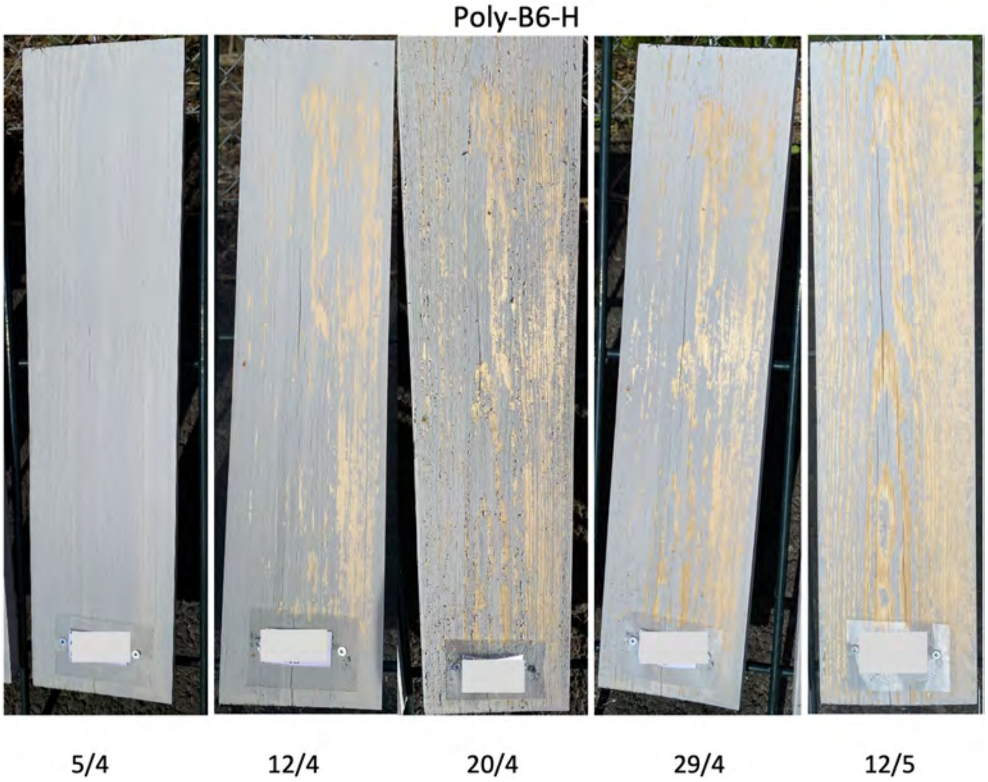


Figure 5.50: Weathering test for *Poly-B6-H* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month* in the figure.

In Figure 5.51, the weathering test on planed boards for *Poly-B2-M* can be seen. The paint had peeled off evenly on the planed board, not solely on specific areas, and compared to the reference paint, it had better durability and adhesion on the planed boards.

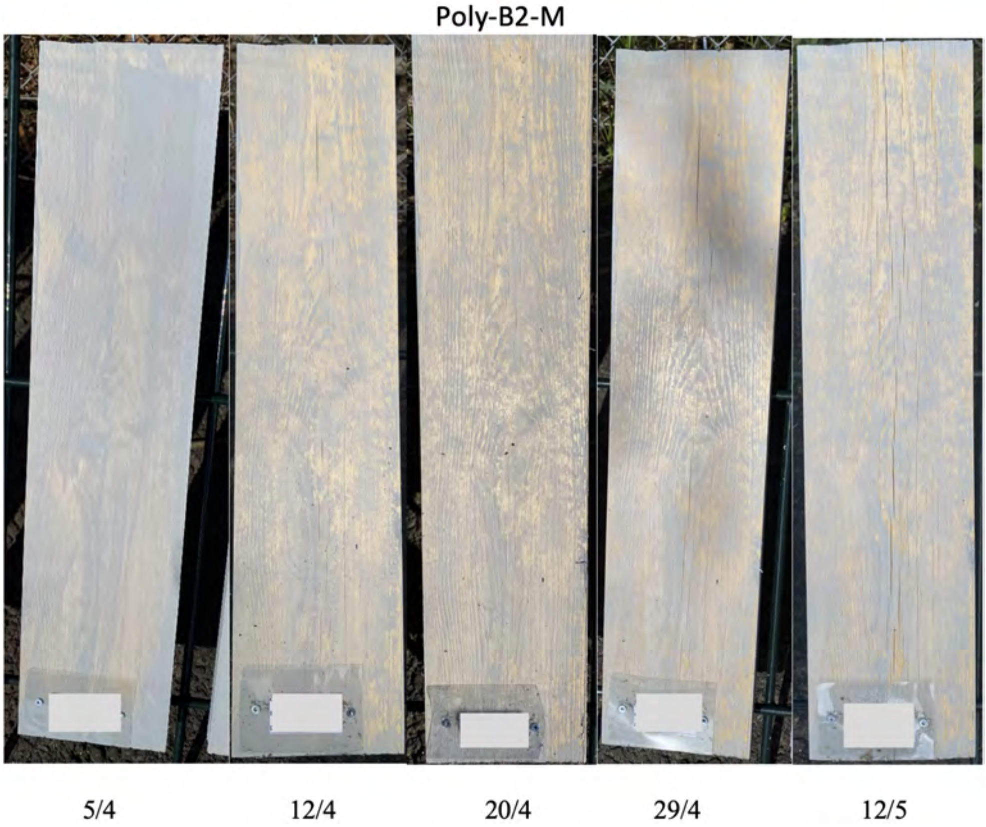


Figure 5.51: Weathering test for *Poly-B2-M* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month* in the figure.

In Figure 5.52, the weathering test on planed boards for *Poly-B2-H* can be seen. Compared to *Poly-B2-M*, the paint had peeled off unevenly on the planed board. Especially, in the top left corner of the board where the adhesion of the paint seemed to poor. Similarly, as *Poly-B2-M* this paint had better durability on planed boards compared to the reference paint, *Poly-Acrylate-Ref*.

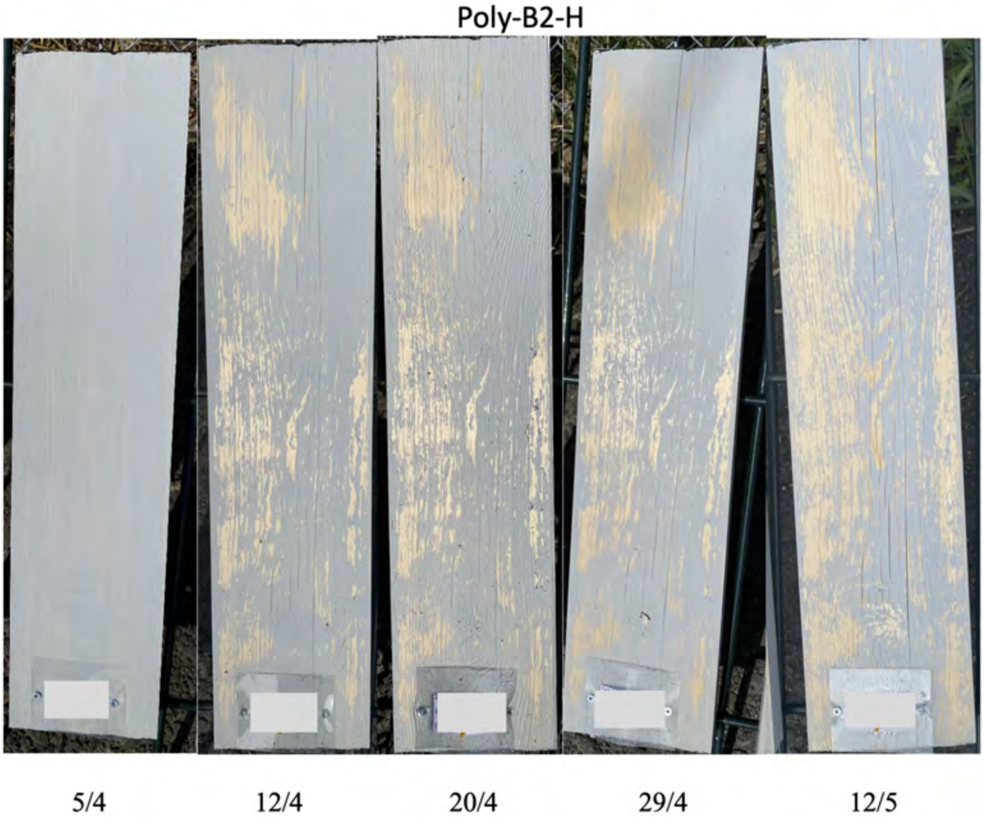


Figure 5.52: Weathering test for *Poly-B2-H* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month*.

In Figures 5.53 and 5.54, are the paints which exhibited low durability on the planed boards displayed. In Figure 5.53, the weathering test on planed boards for *Poly-B5-M* can be seen. As it can be seen in the figure, the paint peeled off quite extensively after only one week. Compared to the reference paint, *Poly-Acrylate-Ref*, the paint had lower adhesion ability and lower durability on the planed boards.

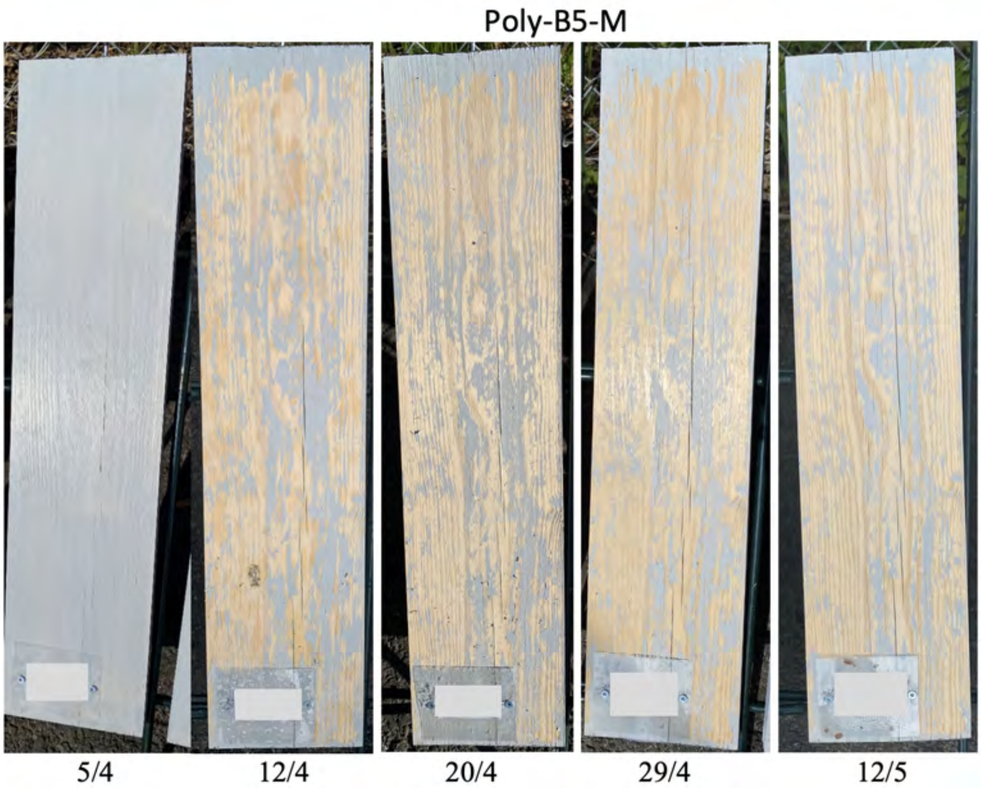


Figure 5.53: Weathering test for *Poly-B5-M* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month* in the figure.

In Figure 5.54, the weathering test on planed boards for *Poly-B5-H* can be seen. In the picture from 12/4, it can been seen that the paint firstly peeled off at the latewood. Further, in the picture from 20/4, it can be seen that the paint was flaking before falling off. In the last picture from 12/5, almost all paint had peeled off from the board. *Poly-B5-H* displayed a lower durability on the planed boards compared to both *Poly-B5-M* and the reference paint, *Poly-Acrylate-Ref*.

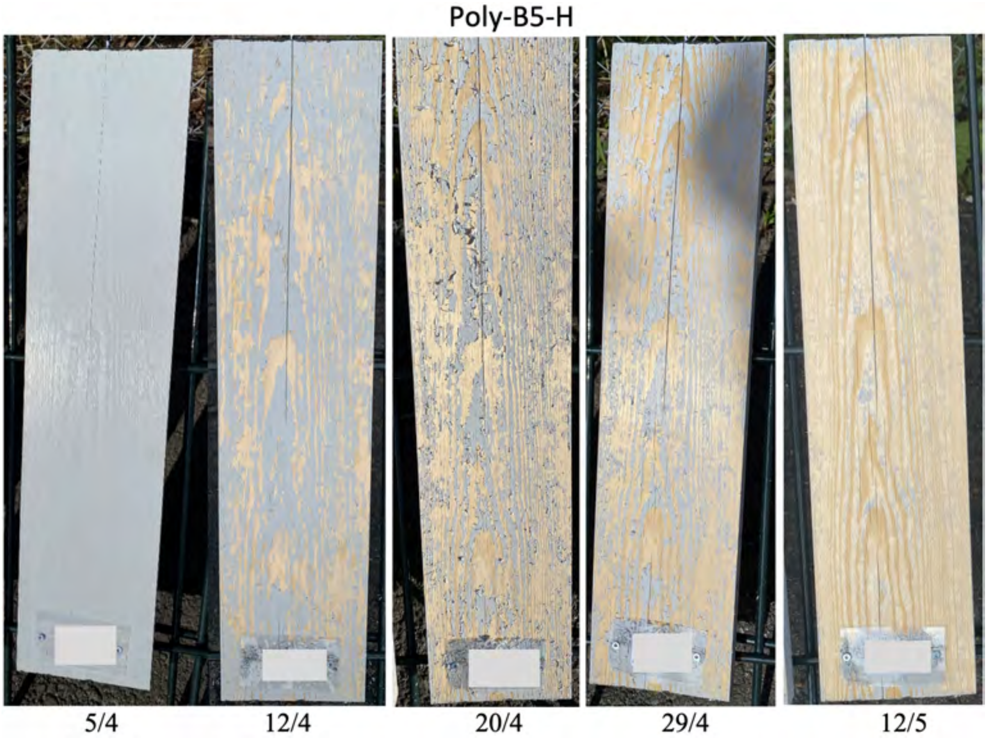


Figure 5.54: Weathering test for *Poly-B5-H* on planed boards. The starting date for the weathering test was April 5, 2022 and the end date was May, 12 2022. The dates are presented in *day/month* in the figure.

5.2.12 Accelerated Weathering Test

In this section the result from QUV accelerated weathering will be presented. In Figure 5.55, the result on the boards after 150 h in the QUV is demonstrated.

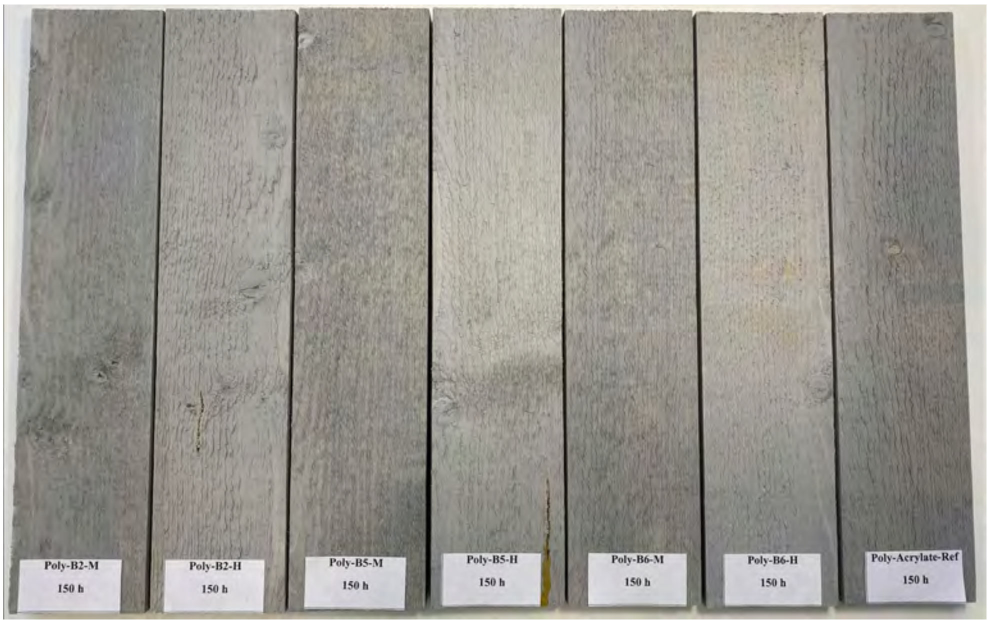


Figure 5.55: QUV accelerated weathering for all polybinder paints for 150 h.

The paints with binder B2, *Poly-B2-M* and *Poly-B2-H*, displayed a good durability of the paints on the boards. No paint had peeled off from the boards, however there was a small crack on the board with *Poly-B2-H* where the paint had peeled off. Further, for *Poly-B5-M* the durability of the paint was good, no paint had peeled off. However, there were sections on the board where the paint had a lighter color compared to the rest of the board. For *Poly-B5-H*, the paint had not peeled off after 150 h. Noteworthy was a crack in the lower right corner on the board where there was resin from the wood. Furthermore, for the paints with binder B6, *Poly-B6-M* exhibited good durability on the board and no paint had peeled off. However, *Poly-B6-H* exhibited a different result compared to *Poly-B6-M*. This paint had two sections in the middle of the board where a lot of paint had peeled off. Lastly, for the reference paint, *Poly-Acrylate-Ref*, the paint exhibited quite poor durability on the board. The paint had peeled of at a knot on the board and there were lighter paint areas on the board.

Further, the durability of the paints was ranked from best to worst, where the value 1 represented the best durability and the value 7 represented the worst durability. The result can be seen in Table 5.9. Note, that the difference of durability for the top four paints in the table were quite similar, see Figure 5.55.

Table 5.9: Ranking of the durability of the polybinder paints on fine sawn boards after 150 h in QUV. The value 1 represents the best durability and the value 7 represents the worst durability.

Paint	**Rank**
Poly-B6-M	1
Poly-B5-H	2
Poly-B5-M	3
Poly-B2-H	4
Poly-B2-M	5
Poly-Acrylate-Ref	6
Poly-B6-H	7

In Figure 5.56, the result of the polybinder paints on the boards after 300 h in the QUV is demonstrated.

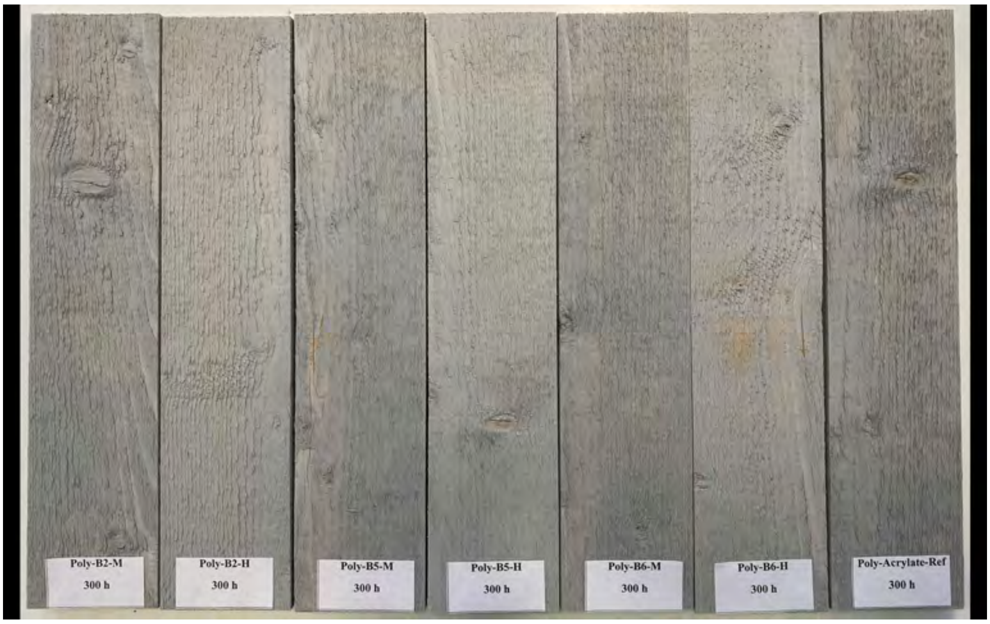


Figure 5.56: QUV accelerated weathering for all polybinder paints for 300 h

Poly-B2-M had started to peel off along the growth rings. Further, for *Poly-B2-H*, there were lighter sections on the board where the paint had started to peel off. However, both paints with binder B2 exhibited good durability at knots on the boards, no paint had peeled off at the knots. Furthermore, *Poly-B5-M* had peeled off at a section of the board. For *Poly-B5-H* the durability of the paint was quite good but the paint had peeled off at a knot. Further, *Poly-B6-M* exhibited good durability of the paint after 300 h in the QUV, no paint had peeled off. However, for *Poly-B6-H* a different result was displayed. This paint had peeled off quite extensively on a section located in the middle of the board. Similar behavior could be seen after 150 h in the QUV, see Figure 5.55. Lastly, for *Poly-Acrylate-Ref* there were lighter areas on the board where the paint had started to peel off. Additionally, the paint had started to peel off at a knot.

Furthermore, the durability of the paints was ranked from best to worst, where the value 1 represented the best durability and the value 7 represented the worst durability. The result can be seen in Table 5.10.

Table 5.10: Ranking of the durability of the polybinder paints on fine sawn boards after 300 h in QUV. The value 1 represents the best durability and the value 7 represents the worst durability.

Paint	**Rank**
Poly-B2-H	1
Poly-B2-M	2
Poly-B6-M	3
Poly-Acrylate-Ref	4
Poly-B5-H	5
Poly-B5-M	6
Poly-B6-H	7

In Figure 5.57, the result of the polybinder paints on the boards after 500 h in the QUV is demonstrated.

Figure 5.57: QUV accelerated weathering for all polybinder paints for 500 h

Poly-B2-M had good durability on the board, no paint had peeled off. However, for *Poly-B2-H*, there are two sections located in the middle of the board where the paint had peeled off. The same behaviour, but less extensively, could be seen for *Poly-B6-H* after 150 h and 300 h in the QUV, where the paint had peeled of at the same section as *Poly-B2-H* after 500 h, see Figures 5.55 and 5.56. The paint had also started to peel off at a knot on the board. Noteworthy is that the texture of the board was quite rough but the paint had still peeled off. Further, for *Poly-B5-M* the paint had good durability on the board after 500 h in the QUV, no paint had peeled off except on a knot where it had started to peel off. For *Poly-B5-H*, the durability of the paint on the broad was not as good as for *Poly-B5-M*. The paint had peeled off along with the growth rings with latewood. Further, for *Poly-B6-M*, the paint had started to peel off at the growth rings with latewood. The paint had also started to peel off at a knot. A similar behaviour was seen for *Poly-B6-H* where the paint had started to peel off from a knot. The paint had also started to peel off from a section of the board where the texture seemed to be less rough than other areas of the board. Lastly, for the reference paint, *Poly-Acrylate-Ref* had started to peel off at some areas located at the middle of the board. Further, *Poly-Acrylate-Ref* had also peeled off from a knot.

Furthermore, the durability of the paints was ranked from best to worst, where a value of 1 represented the best durability and value of 2 represented the worst durability. The result can be seen in Table 5.11.

Table 5.11: Ranking of the durability of the polybinder paints on fine sawn boards after 500 h in QUV. The value 1 represents the best durability and the value 7 represents the worst durability.

Paint	**Rank**
Poly-B2-M	1
Poly-B5-M	2
Poly-Acrylate-Ref	3
Poly-B6-M	4
Poly-B6-H	5
Poly-B5-H	6
Poly-B2-H	7

To sum up, after 150 h in the QUV, *Poly-B6-M* exhibited the best durability on the boards of all polybinder paints, while *Poly-B6-H* displayed the worst. Noteworthy, were the two sections located in the middle of the board where *Poly-B6-H* had peeled off. Further, after 300 h in the QUV, *Poly-B2-H* displayed the best durability. The paint exhibited good durability on knots. *Poly-B6-H* displayed the worst durability after 300 h and there were two section, located in the middle of the board, where the paint had peeled off. Lastly, after 500 h in the QUV, *Poly-B2-M* displayed the best durability of the polybinder paints on the board, while *Poly-B2-H* exhibited the worst. Noteworthy was that *Poly-B2-H* had peeled off extensively from sections located at the middle of the board.

5.3 Environmental Assessment

This section presents the environmental assessment for the selected binders in the monobinder and polybinder paints. The binders was purchased by Sioo Wood Protection from different manufacturing sites. As mention in section 3.12, the environmental assessment was limited to only examine the impact from the manufacture and transportation of the binders to Sioo Wood Protection. The total transportation includes transportation of the silane/siloxane to the manufacturing site for the binder, and the transportation for the binder to Sioo Wood Protection. The different types of transportation for the binders and silane/siloxane can be seen in Appendix C. Note, error bars are not included in the figures.

5.3.1 Monobinder Paints

In the following section the environmental impact of the binders in the monobinder paints are presented. The environmental impact is calculated for manufacture and transportation of the binders in the paints. The impact of each binder is independent of color, hence the paints will be named after type of binder and PVC, for example *B2-20%* will refer to all monobinder paints containing binder B2 with PVC 20%.

In Figure 5.58, the *Global Warming Potential* (GWP) for the manufacture of the binders in the monobinder paints is presented. The impact is expressed in *kilogram carbon dioxide equivalents* [$kg\ CO_2\ eq$]. *B5 20%* displayed the highest impact during manufacturing of the binder, while *B6 30%* exhibited the lowest. The reference paint *Acrylate 20%* exhibited average impact, while *Acrylate 30%* displayed the second lowest impact. Noteworthy is that *B5 30%* displayed higher impact than several monobinder paints with PVC 20%, and *B6 20%* displayed lower impact than several monobinder paints with PVC 30%.

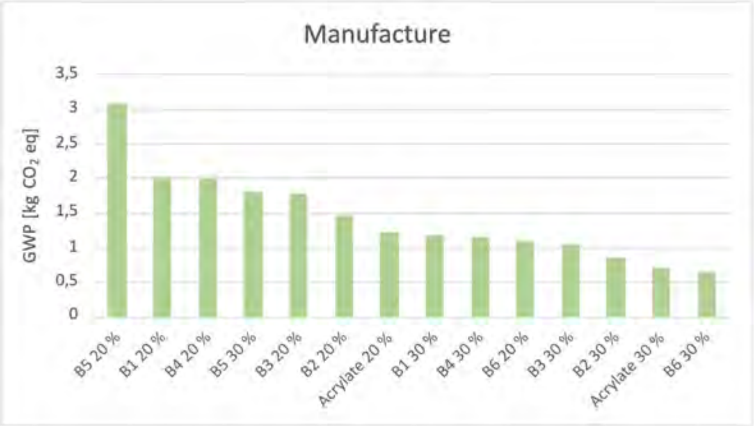
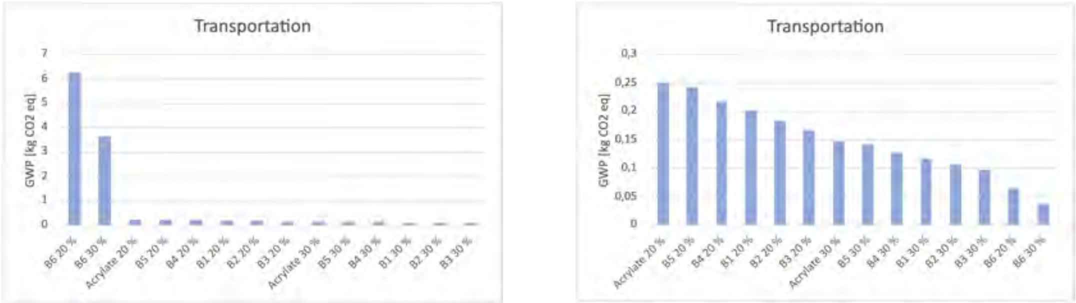


Figure 5.58: Global Warming Potential (GWP) for manufacturing of the binders in monobinder paints. The impact is presented in *kilogram carbon dioxide equivalents* [$kg\ CO_2\ eq$].

In Figure 5.59, the environmental impact for the transportation is presented. The transportation includes the transport of the silane/siloxane to the manufacturing site of the binder, and the transport of the binder to Sioo Wood Protection. In Figure 5.59a, the impact from transportation of all binders in the monobinder paints is displayed. Binder B6 is currently transported by aircraft and thus, has the highest impact.

Figure 5.59b demonstrates the environmental impact for transportation of all monobinder paints when binder B6 is instead transported by ship. As can be seen in the figure, the impact drastically decreases for the paints with binder B6, both *B6 20%* and *B6 30%* displayed the lowest impact. Noteworthy is that *B6 20%* displayed lower impact than the monobinder paints with PVC 30%. Moreover, the reference paint, *Acrylate 20%*, displayed the highest impact.



(a) GWP for the transportation of the binders in the monobinder paints.

(b) GWP for the transportation of the binders in the monobinder paints, where binder B6 is transported by ship.

Figure 5.59: Global Warming Potential (GWP) for the current transportation of the binders in the monobinder paints. The transportation includes both the transport of the silane/siloxane to the site for manufacturing of the binder, and the transport of binder to Sioo Wood Protection. The impact is presented in *kilogram carbon dioxide equivalents* [*kg* CO_2 *eq*].

5.3.2 Polybinder Paints

In this section the environmental impact for the polybinder paints is presented. The environmental impact is calculated for the manufacture and transportation of the binders in the paints.

In Figure 5.60, the global warming potential for the manufacture of binders in the polybinder paints is presented. *Poly-B5-H* displayed the highest impact followed by *Poly-B5-M*, while *Poly-B6-H* displayed the lowest impact. Generally, when all acrylate had been substituted with one of the selected binders the impact increased. However, for the polybinder paints with binder B6 the opposite correlation could be seen.

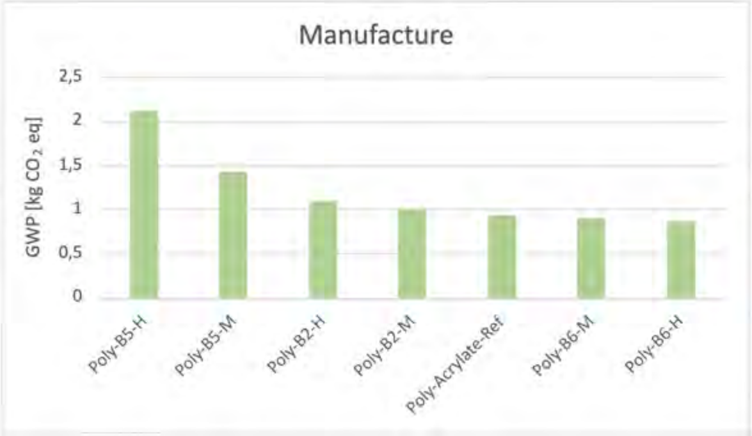
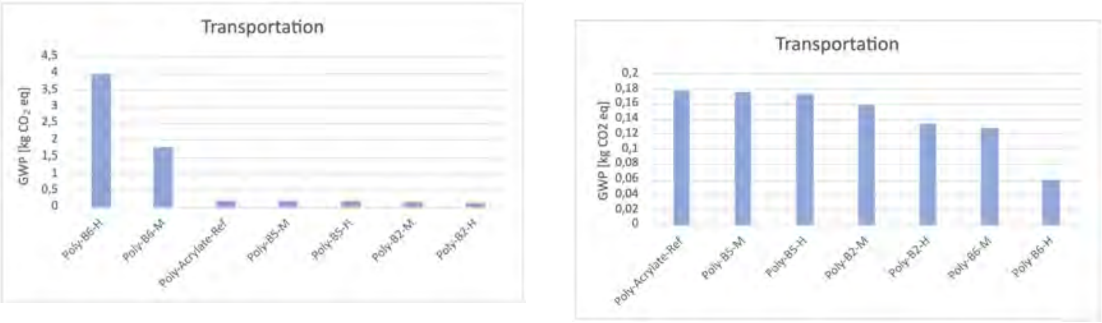


Figure 5.60: Global Warming Potential (GWP) for the manufacturing of the binders in the polybinder paints. The impact is presented in *kilogram carbon dioxide equivalents* [*kg* CO_2 *eq*].

In Figure 5.61, the environmental impact for the transportation is presented. Similarly as for the monobinder paints, the transportation includes both the transport for the silane/siloxane and the transport for the binder. In 5.61a, the transportation impact is presented, where binder B6 is transported by aircraft. Thus, the polybinder paints with B6 exhibited the highest impact. A general behaviour seen was that when all acrylate content had been substituted with one of the selected binders, the obtained impact was lower. However, for the polybinder paints with binder B6, the opposite correlation was seen. In Figure 5.61b, the transportation impact is presented where binder B6 is instead transported by ship. As it can be seen in the figure, the impact drastically decreases for the paints with binder B6. Both *Poly-B6-M* and *Poly-B6-H* exhibited the lowest impact of all polybinder paints. The reference paint, *Poly-Acrylate-Ref*, displayed the highest impact. Generally, all polybinder paints containing acrylate had higher impact compared to the paints where all acrylate had been substituted by one of the selected binders.



(a) GWP for the current transportation for the binders in the polybinder paints, where binder B6 is transported by aircraft.

(b) GWP for the transportation for the binders in the polybinder paints, where binder B6 is transported by ship.

Figure 5.61: Global Warming Potential (GWP) for the transportation for the binders in the polybinder paints. The transportation includes both the transport of the silane/siloxane and the transport of the binder. The impact is presented in *kilogram carbon dioxide equivalents* [$kg\ CO_2\ eq$].

6

Discussion

A paint cannot only be durable as dry paint, the paint needs to be stable as wet paint as well. Therefore, when testing the function of paint, it is important to both perform testing on wet and dry paint. Desirable properties of wet paint is homogeneous bulk properties and shear thinning behavior. The paint has to be easy to handle for the users during application. Consequently, viscosity is a significant property to investigate because e.g. control of flow is necessary for accomplishing a successful finish, see Section 2.10. Unwanted properties in wet paint are for example flocculation, sedimentation and phase separation of the paint, see Section 2.10. Desirable properties of dry paint is for example high adhesion durability on the substrate, see Section 2.11.2, and aesthetically pleasing appearance. The dry paint has to be able to sustain stress from for example weather and wear. Further, SiOO:X paints should be matt hence gloss and color are important properties to investigate. The mentioned wanted/unwanted properties are functional properties that will be analyzed for all investigated binders. A part from desirable functional properties, in a world with accelerating climate change, sustainability is an important perspective to analyze. Transportation and manufacture of binder can be areas that affect the climate change and should therefore be considered before incorporating a new binder for paint production. All binders will, therefore, be discussed based on impact of transportation and manufacture to evaluate the most sustainable choice based on these two categories. Other areas, that may have an impact on the environment, will not be discussed but could be of equal importance.

The following sections will provide a summary of the extensive result to easier demonstrate paint properties of each investigated binder. First, the binder content in the investigated binders will be discussed and thereafter summarizing results of binders in monobinder paints and polybinder paints will follow, see Sections 6.1, 6.2 and 6.3. The most important results will be discussed, see Section 6.2.8 and 6.3.5. Moreover, the environmental impact of each binder in monobinder and polybinder paints will be summarized and discussed, see Section 6.4. Lastly, possible errors and future work will be discussed, see Sections 6.5 and 6.6.

6.1 Binder Content

The content of the investigated binders are for the most part unknown and not provided by the companies that distribute the products to Sioo Wood Protection. However, some parts of the content have to be provided by the producers if there is a risk of e.g. health hazard. This information is usually provided by a *Safety Data Sheet* (SDS). For some of the binders, a cyclosiloxane group in low concentrations was present in the binder content list. Cyclosiloxane is a health hazard to humans and to the environment, hence this product is usually distilled away. The process is harder and more costly if there are some molecules with similar volatility. A long siloxane polymer has high molecular weight and will be a non-volatile substance, however a lighter substance for example a monomeric silane or short-chained siloxane polymer will be more volatile. Thus, a cyclosiloxane and a silane will be harder to separate by distillation. Therefore, there is a suspicion that binders which contain a cyclosiloxane compound also contain a larger amount of monomeric silanes or short chained siloxanes than binders which do not contain cyclosiloxanes in significant amounts. The reasoning is strengthened by the behavior of the different binders.

6.2 Monobinder Paints

This section contains a summary of the results for every binder in the monobinder paints, see Sections 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.2.5, 6.2.6 and 6.2.7. In Section 6.2.8, discussion about the cause and significance of the results from monobinder paints will be discussed more thoroughly. Furthermore, in Section 6.2.8, a motivation will be given for selection of binders to proceed with for the production of polybinder paints. For short information about each binder, including physical data and observations during the project, see Appendix A.

6.2.1 Acrylate Binder

The monobinder paints with acrylate were not stable as wet paints. The stability test separated after only one day, for example, the stability test of monobinder paint, *Gray Acrylate 20%* had separated a lot, see Figure 5.5a. The stability was gently stirred with a wood stick and resistance to movement were noted for the bottom layer. This could be because the binder and white pigment had formed a sediment at the bottom. The corresponding gray paint with PVC 30% had also separated but not to the same extent, see Figure 5.5b. Generally, all acrylate monobinder paints had low viscosity. Thus, the paints were quite hard to handle, they were quite runny when painted. On the other hand, the paints flowed out on the boards well. This was seen on leneta paper as well, the acrylate monobinder paints formed a smooth film on leneta paper. Moreover, the paints with acrylate had intermediate foaming compared to the other monobinder paints. The amount of surfactants in the binder could have affected this or the mixing speed during the formulation of acrylate monobinder paints.

The result in the cross hatch testing was beneficial. However, in the weathering test the boards with acrylate pealed off from the boards. Probably due to swelling and shrinking in the wood which does not occur in wood to the same degree indoors. The acrylate binder was probably too stiff to endure the enlargement and shrinking of the surface area. However, the stiffness of the acrylate binder were unexpected because acrylate polymers usually have high elasticity. However, the actual type of acrylate copolymer used in the binder is unknown. It is only stated in the *Technical Data Sheet* (TDS) that the binder is a self-crosslinking acrylic dispersion in water and contains as few reactive film improving co-solvents as possible. An emulsion paint usually contains one acrylate polymer which provides hardness and one that provides softness to the material. Perhaps the hard component was present in too large amount and the soft component in too low amount. Another explanation could be that there were too low amount of reactive film improving co-solvents to make an elastic film. Furthermore, the surface condition of the board used could also matter, wood is an anisotropic material. The board used could have had wider, prominent bands of latewood which made the paint peel off faster, see Section 2.5.

Considering the appearance of the dry paint, the monobinder paints with acrylate typically had high amount of gloss on the boards, and generally the highest gloss compared to the other monobinder paints. Especially the yellow paints had high gloss values. The paints with acrylate had higher gloss on leneta paper than on the boards. The paints formed a film on leneta paper, consequently there should be low influence of gloss from the leneta paper underneath. Non-coated holes in the film could otherwise lead to influence of the paper underneath. However, on leneta paper, the acrylate paints only displayed an average amount of gloss compared to the other monobinder paints. Looking at the color of the wet paints, the shade was generally darker than the monobinder paints with other binders. In particular the black and yellow paints were dark, in fact they were the darkest monobinder paints of all monobinder paints. The color of the dry paints were slightly different, the yellow paints were considerably lighter than the wet paints. Monobinder paint, *Yellow Acrylate 30%* was the second lightest paint of all yellow monobinder paints. An explanation for the big change in lightness during drying, compared to the other monobinder paints, could be due to low viscosity of the acrylate monobinder paints. Light pigment could have sedimented during color measurement, the bulk color measured would therefore be darker than if the pigments were homogeneously dispersed in the wet paint. The pigments were perhaps more dispersed in the dry film from acrylate monobinder paints than the pigments in dry film from other monobinder paints, hence resulting in a rather light paint film. Considering the solid content of the acrylate monobinder paints, yellow paints generally had higher content than the other colors. The PVC was calculated based on pigment volume, not the solid content of the different pigment formulations used (i.e. Carbon Black, Titanium dioxide and Iron oxide). Thus, it is expected that paints of different colors will have different solid content.

In summary, the wet paints of the acrylate monobinder paints did not have long-term stability, were hard to handle but had a good flow out on the boards. Furthermore, the wet paints were amongst the darkest monobinder paints. Considering the result from testing of the dry paints, the acrylate paints did not have high durability on the boards, had high amount of gloss and were quite light colored.

6.2.2 Binder B1

The foam decrease in the monbinder paints with binder B1 was quite extensive. Hence, a lot of foam was created during the production of the paints. The produced paints generally had the lowest viscosities of all monobinder paints, see Figure 5.11, but for some shear rates the paints with acrylate had lower viscosity. Specifically, every monobinder paint with binder B1, independent of color, with PVC 20% had the lowest viscosity of all monobinder paints, see Figure 5.11. In practice, this resulted in very runny paints which were hard to handle. Especially, the yellow paints were very runny. Although, only the paints with a PVC 20% left saggy films on leneta paper, the paints with PVC 30% were smoother. The sagging behavior of the paints can be observed for *Yellow B1 20%*, see Figure 5.21a. Note that all paint films on leneta paper in this study dried horizontally, hence should not be confused with a *sag resistance test*.

Similarly to the monobinder paints with acrylate binder, the monobinder paints with binder B1 had phase separation. The phase separation is noteworthy as both the paints with B1 and acrylate had very low viscosity, indicating the relationship between low viscosity at low sheer rates and poor paint stability. Moreover, precisely as the gray acrylate monobinder paints, *Gray B1 20%* had separated to great extent and a lot more than the corresponding gray paint with PVC 30%, see Figure 5.1. A lot of the white pigment had formed a sediment at the bottom. The sediment probably contained the binder as well. Furthermore, *Yellow B1 20%* also contained phase separation but not to the same degree, a white thin layer could be seen at the surface. *Yellow B1 30%* and the black B1, on the other hand, paints had no phase separation. However, it is difficult to see in the black B1 paints if phase separation has occurred due to the black pigment.

Considering the preparation of the boards for the weathering test, the effect of low viscosity was also noticed for the application of the paints on the planed boards. As previously mentioned, the paints were quite runny, thus difficult to apply the right amount of paint to the boards. The paint did not really stick to the board as wet paint and ran off when the amount of paint reached a certain level. Furthermore, the coating of the dried black paints was very sensitive. The paint came off quite easily and fingerprints were left on the coating when touched. This behavior has only been observed for the B1 monobinder paints and was strengthened by the cross hatch test. All black B1 monobinder paints were classified as a 4 which represents the second lowest adhesion ability. The same value was given to the gray paints. The yellow paints only had slightly better adhesion in the cross hatch test. The poor result in the cross hatch test contradicts the weathering test where the B1 monobinder paints gave a desirable result, the coating did not peel off as much compared to other monobinder paints.

Considering the appearance of the paints with binder B1, they were generally matt on the boards and had lower gloss than the monobinder paints with acrylate. On leneta paper, the yellow and gray monobinder paints with binder B1 had a lot of gloss, for example *Yellow B1 20%* had a gloss value of 74 GU. The black paints were much matter, for example *Black B1 30%* only had a value of 9 GU. Considering the paint films on leneta paper for the B1 paints with PVC 20%, they were not optimal for gloss measurements. The films had a saggy appearance. Similarly, the paints with PVC 30% were not optimal, the leneta paper could be seen through the paint film. Consequently, the gloss of the leneta paper underneath could have effected the gloss measurement of the paints. Note, the leneta paper has really high gloss, approximately 90 GU, hence, the gloss of the leneta paper could explain why the gray and yellow monobinder paints were much matter on the boards than on leneta paper. The boards only had a gloss of 11 GU with two layer of Wood Protection.

Regarding the color of the wet paint, *Gray B1 20%* was the darkest paint of all monobinder paints, see Figure 5.12. As previously mentioned, the stability test from *Gray B1 20%* had extensive phase separation where white pigment had separated to the bottom. Perhaps this behavior of the white pigment affected the color measurement. The paints were stirred before color measurement, however, some white pigment might have sedimented during the color measurement. For *Gray B1 30%* the phase separation was not as extensive and consequently the paint was the forth lightest monobinder paint. Furthermore, *Yellow B1 30%* was the third darkest paint of the yellow monobinder paints and *Yellow B1 20%* was the fourth lightest paint, see Figure 5.13. As previously mentioned, *Yellow B1 20%* had phase separation in the stability test where light pigment had separated to the surface, whereas *Yellow B1 30%* had no phase separation. This further strengthens that separation of pigments can affect the results from color measurements. The black paints were equal in lightness and had an average lightness in comparison with the other black monobinder paints. The black B1 monobinder paints were slightly darker as dry paints. The same was noticed for the yellow and gray B1 monobinder paints. Hence, the lightness is not dependent on the two PVC's in this case. Noteworthy was that *Gray B1 20%* was the darkest monobinder paint both as wet paint and as dry paint on the board. Moreover, regarding solid content, the yellow B1 monobinder paints had higher solid content than the black and gray paints. The same explanation as for the acrylate monobinder paints is applicable; PVC was calculated based on pigment volume, not the solid content of the different pigment formulations used (i.e. Carbon Black, Titanium dioxide and Iron oxide). Thus, it is expected that paints of different colors will have different solid content.

In summary, although the B1 paints were quite hard to handle and gave poor results in cross hatch testing, the results from the weathering test were quite good. However, the stability as wet paints was problematic and most paints exhibited phase separation. Perhaps *Yellow B1 30%* could be an alternative, the paint was the only B1 paint which had no phase separation, excluding the black B1 paints where phase separation was hard to detect. This paint was stable as a wet paint and gave adequate results in the weathering test. However, the yellow B1 monobinder paints were quite glossy so a matting additive could be needed. Lastly, the B1 monobinder paints displayed extensive foaming, consequently a defoamer could be needed.

6.2.3 Binder B2

The newly formulated monobinder paints with binder B2 contained a low amount of foam. Only a few bubbles could be observed in the paint. However, those bubbles were more stable than the foam in the B1 monobinder paints. The stability test showed that very few B2 monobinder had phase separation, however potential creaming in the stability test for *Black B2 20%* was noticed after a couple of weeks. Further, phase separation for *Yellow B2 20%* was noticed, a darker yellow layer was detected at the bottom. The phase separation was noticed after the production of polybinder paints had been initiated. Hence, this result was not taken into consideration when the selection was made.

A characteristic feature for the wet B2 paints was high viscosity e.g. *Black B2 20%* had the highest viscosity of all monobinder paints. High viscosity in the B2 paints was not unexpected since the binder on its own felt really viscous when stirred during the paint production. The binder was quite sticky and consequently harder to handle during the paint production than binder B1. On the other hand, the final paints were easier to handle than the B1 monobinder paints. The B2 monobinder paints were not as runny as the B1 paints, especially compared to the B1 paints with PVC 20%, making the application on the boards easier.

Considering the paint film on leneta paper, the B2 paints created smooth and even paint films. The small holes detected in the coatings, see Figure 5.22, could possibly be fisheyes from lack of surface tension decreasing polymers in the paint. This was a characteristic feature for the B2 paints and has to be taken into consideration during production. Perhaps additives have to be added to compensate for the lack of surface tension decreasing polymers. Moreover, since the foam test exhibited low foam decrease for all B2 monobinder paints, a conclusion could be made that the holes should not be due to high degree of foam in the paints.

While noting that the previously mentioned fisheyes in the coatings could have affected the measurements, the gloss of the B2 paints were low, especially for PVC 30%. However, the black paints had slightly higher gloss than the gray and yellow paints. Regarding color of the wet B2 monobinder paints, the gray and yellow paints were fairly light compared to the other gray and yellow monobinder paints. In fact, *Gray B2 30%* was the lightest gray paint of all monobinder paints and *Yellow B2 20%* was the lightest paint of all monobinder paints. On the other hand, the black paints were slightly darker than average in regard to all monobinder paints. The lightness of the gray B2 paints could be because they had no phase separation. From the stability tests, it was observed that white pigment usually sedimented to the bottom, consequently with less phase separation more white pigment will be present in the bulk and the overall appearance of the paint will be lighter. The same reasoning goes for *Yellow B2 20%*, where a darker layer could be seen at the bottom, thus the upper layer is lighter. The color of the dry B2 monobinder paints on the boards showed that *Gray B2 20%* and *Gray B2 20%* had similar lightness which was of average lightness compared to the other monobinder paints. Moreover, the black B2 monobinder paints were the lightest paints of all black monobinder paints.

The black paint had a minor change in lightness from wet to dry paint compared to the other black monobinder paints.

Regarding the durability of the dry B2 monobinder paints, the results from cross hatch testing were quite diverse. *Black B2 30%* gave the worst result and was classified as a 5. The other B2 monobinder paints gave better results, the yellow and gray paints were ranked a 3, consequently average performance. The best B2 monobinder paint in cross hatch testing was *Black B2 20%* which was classified as a 2 which is slightly better than average. The B2 monobinder paints gave better results in the weathering test, although the coatings started to peel off at the growth rings. Lastly, similarly to the B1 monobinder paints, the yellow paints had a higher solid content compared to the black and gray paints. The same explanation as for the acrylate monobinder paints is applicable; PVC was calculated based on pigment volume, not the solid content of the different pigment formulations used (i.e. Carbon Black, Titanium dioxide and Iron oxide). Thus, it is expected that paints of different colors will have different solid content.

To sum up, the B2 monobinder paints had mostly good results as wet paints e.g. good stability and easy to handle. However, the binder solely was quite sticky and slightly hard to handle. Furthermore, the paints had good durability in the weathering test, although some paints started to peel off at the growth rings. Moreover, the B2 paints had a matt appearance on the boards. Noteworthy for the B2 paints is the characteristic feature of fisheyes in the paint coatings.

6.2.4 Binder B3

Binder B3 gave beneficial results both as a wet and dry paint on the boards. The result concerning the wet paint was unexpected because binder B3 contains a coupling agent, other binders with coupling agent had phase separation or coalescence in the stability test. Furthermore, there was generally low amount of foam formed during the paint production of B3 monobinder paints, see Table 5.2. Low amount of foam could indicate that binder B3 contained low amount of surfactants compared to the other binders or low mixing velocity during production. The reason could also be a combination of low amount of surfactants and low mixing velocity. However, the foam present was quite stable, similar to monobinder paints containing binder B2. After several days of unchanged appearance, the paint was slowly stirred until all foam had disappear, in order to proceed with testing of the paint.

The viscosity of B3 monobinder paints was generally lower than average compared to all monobinder paints, see Figure 5.9a. Moreover, the paints were homogeneous and had no phase separation in the stability tests. Although, small black dots were present on the surface of the gray paints. Furthermore, the B3 monobinder paints did not form smooth films on leneta paper. The films contained several holes without paint, the spread of holes was more extensive than for the B2 monobinder paints. Especially, *Black B3 30%* had a large number of holes in the film. The holes could be due to lack of surface tension decreasing polymers in the binder or due to foam present in the paints during application. However, the holes had a different appearance than the holes present in the films formed by the B2 monobinder paints. The appearance was not similar to fisheyes and the holes were only present on leneta paper not on the planed or fine sawn boards. Even though the B3 monobinder paints formed heterogeneous films on the leneta papers, the paints formed smooth coatings on the boards. In addition, the B3 monobinder paints had high durability in the weathering test. Although, characteristic cracks in both the coating and the wood could be seen. Furthermore, the yellow paints were classified as a 1 in the cross hatch testing which represents high adhesion to substrate. However, the gray and black paints had low adhesion to substrate. The black paints were ranked as 5:s, representing the lowest adhesion strength in the test. The gray paints got slightly better results, although were still classified as a 4 and a 3. Conclusively, B3 monobinder paints performed better in weathering test than in cross hatch testing. Due to the holes in the film, gloss measurement on leneta paper was quite difficult to operate and was not possible for monobinder, *Black B3 30%*. However, the other B3 monobinder paints had low gloss compared to all monobinder paints. Furthermore, the gloss on the boards was generally the lowest compared to all monobinder paints. Especially, the black paints had low amount of gloss, see Figure 5.27.

To summarize, the B3 monobinder paints displayed unexpected good results as wet and dry paints. They had high stability as wet paints and had high durability in the weathering test. Furthermore, the paints had a desirable low amount of gloss. However, the films on leneta paper contained several holes.

6.2.5 Binder B4

A characteristic feature for binder B4 was the stickiness of the binder and consequently the formulated paints were sticky as well. The stickiness was a recurring problem during formulation, handling and testing of B4 monobinder paints. The binder stuck to lab equipment quite excessively, making it difficult to pour the right amount into the dissolver as it stuck to the sides of the measuring cylinder. Furthermore, the binder did not disperse well in the paint and stuck to the blade of the dissolver which created lumps in the paints. Moreover, cleaning of lab equipment after the use of binder B4 was quite difficult. Furthermore, the coating from monobinder paints with binder B4 resulted in uneven films, see Figure 5.23. This was due to the stickiness of the binder. When the B4 monobinder paints were applied to the boards or leneta paper, small, sticky lumps appeared. These lumps stuck to the applicator used for the application of paint on leneta paper and made the films uneven. This was especially visible for monobinder paint, *Gray B4 30%* in Figure 5.23b, where streaks in the film could be seen. On the boards, the sticky lumps became more extensive when more paint was applied. The lumps can be observed in Figure 5.35. Additionally, the paintbrushes were hard to wash, grains of binder stuck to the brush and could not be removed, not even with dish soap. Moreover, the B4 monobinder paints generally had high viscosity making them less runny in application on the boards. However, the sticky lumps were problematic and could make it hard for users to handle the paint. Noteworthy was the viscosity of *Yellow B4 20%* which was very low. Considering the weathering test, the B4 paints generally exhibited low durability where the paint coatings had peeled off quite extensively especially along the latewood. However, *Yellow B4 20%* displayed the opposite and had quite strong durability.

The gray och black B4 monobinder paints had no foam decrease at all. The yellow paints, on the other hand, had high foam decrease. *Yellow B4 20%* had a decrease of 27.27%, while *Yellow B4 30%* had a decrease of 9.52%. Perhaps this could be due to higher mixing speed for the yellow B4 paints, thus giving a higher foam content. Moreover, a special feature seen for the B4 monobinder paints was gelation in the stability tests. Perhaps, this feature could be linked to the stickiness of the binder or the presence of a coupling agent in the B4 binder content. The coupling agent is reactive and can form crosslinking in the paint, consequently leading to gelation. However, despite the gelation, all tests were homogeneous in color and no phase separation was detected. Furthermore, the lightness of the wet B4 monobinder paints, varied depending on color. The gray B4 paints were quite dark compared to all gray monobinder paints. While, the black B4 paints were quite light compared to all black monobinder paints. For the yellow B4 monobinder paints, average lightness was obtained. Considering the gloss of the B4 monobinder paints, the gloss was quite high on leneta paper and quite low on the boards. The high values obtained on leneta paper were possibly due to the sticky lumps in the paints which gave uneven paint films. Consequently, the high gloss of the leneta paper probably affected the measurement, resulting in higher gloss values for the B4 monobinder paints.

To sum up, the B4 monobinder paints would be quite hard for producers and users to handle due to the sticky behavior of the binder. In addition, the paints were not stable as wet paints and gelation was formed in the stability tests. This was a characteristc feature for binder B4 and was not seen for any of the other investigated binders. Moreover, the B4 monobinder paints exhibited low durability in the weathering test.

6.2.6 Binder B5

The monobinder paints with binder B5 were stable as wet paints. The stability test for all paints exhibited a homogeneous color and contained no phase separation. As mentioned in Section 5.1.1, the tests had been exposed to sunlight and consequently there were water drops on the lid and sides of the plastic cup. For the black and yellow stability tests there were also a layer of translucent liquid on the paint surface, probably a layer of water. Noteworthy is that despite the exposure to sunlight the stability tests had no phase separation. Hence, this was taken into consideration when choosing the binders to proceed with in the polybinder paints. However, the B5 monobinder paints contained the second highest amount of foam, see Table 5.2. Only the B1 monobinder paints had a higher degree of foam. This could be due to high velocity during production of the paints or high amount of surfactants in the binder.

The viscosity of the B5 paints were similar to the viscosity for the B3 paints. A general behaviour, was that the yellow paints had lower viscosity compared to the black and gray paints with the same PVC, see Figure 5.9b. The observation was noticed for both the paints with PVC 20% and 30%. Moreover, the B5 paints were easy to apply on the boards. They were not too runny and flowed out well on the boards. Furthermore, the B5 paints also created a smooth continuous paint film on leneta paper, see Figure 5.24. This was a characteristic property for the B5- and the acrylate paints compared to the other monobinder paints which had slightly more incoherent paint films.

Considering the appearance of the dry paint, the B5 monobinder paints typically had high gloss. In fact, they had the highest amount of gloss on the boards except for *Yellow Acrylate 20%* which had higher. A general behaviour was that the paints with PVC 20% had higher gloss than the paints with PVC 30%, see Figure 5.27e. On leneta paper, the B5 paints displayed even higher amount of gloss, but not the highest. However, as mention before, the B5 paints created smooth continuous paint films. Therefore, an assumption could be made that the gloss values obtained on leneta paper with the B5 paints could be more accurate compared to the other monobinder paints. Regarding color of the wet B5 monobinder paints, one noteworthy discovery was that *Gray B5 20%* did not change the lightness of color between wet and dry paint. Consequently, it could be easier to correlate the wet paint with finished result during production. However, further testing has to be made to determine this, other factors could influence the lightness e.g., solid content.

Furthermore, the durability of the paints during the weathering test was good. The paints exhibited good adhesion and durability on the boards. Noteworthy was that there were visible cracks in the boards similarly as for the B3 monobinder paints, see Figure 5.36. The cross hatch test on the other hand, contradicted the result from the weathering test. In fact, all B5 monobinder paints exhibited quite poor adhesion to the boards. All paints were classified as 5 except for *Yellow B5 30%* which was classified as 4. Lastly, the solid content for the B5 paints were quite average compared to the other monobinder paints. The paints with PVC 20% had a solid content between 29 and 34%, while the paints with PVC 30% had a solid content between 20 and 26%. Generally, the yellow paints exhibited a higher solid content compared to the black and gray paints.

To summarize, the B5 monobinder paints displayed desirable results as wet paints and strong durability in the weathering test. Together with the acrylate paints, the B5 paints were the only paints which obtained smooth continuous paint films on leneta paper. One drawback with the B5 paints was that they exhibited the highest gloss values out of all monobinder paints, a undesirable property in paints produced by Sioo Wood Protection.

6.2.7 Binder B6

Distinctive for the monobinder paints with binder B6 was that 200 ml was produced instead 2000 ml as for the other monobinder paints. Moreover, the B6 paints were only produced in gray and black colors. These special conditions were taken into consideration when comparing the results for the paints with binder B6 with the rest of the monobinder paints.

The B6 paints contained the third highest level of foam. Especially for *Black B6 20%*, the foam content was high with a foam decrease of 39.47%. This could be because the immersion blender, used to formulate the B6 monobinder paints, had higher mixing speed than the dissolver. Furthermore, in the stability test the paints exhibited good stability as wet paints. All paints had a homogeneous color and no phase separation was detected. Noteworthy for the stability test was that the foam tests were used as stability tests for the B6 paints. This could affect the results obtained from the stability test. A more accurate result would have been obtained if the stability test was taken after the foam had disappeared. The paint in these stability tests probably contained higher concentration of surfactants than in the 200 ml paints. This can be assumed since foam usually contain high amount of surfactants and could therefore influence the result.

The viscosity of the B6 paints was below average, only the acrylate and B1 paints exhibited lower viscosity. A general behaviour which could be seen was that the gray paints had lower viscosity compared to the black paint with the same PVC, see Figure 5.9b. Moreover, the paints were easy to apply on the boards. The paints had high coverage and not much paint was needed to cover the whole surface of the board. Furthermore, the B6 paints created a good paint film on the leneta paper, similar to the acrylate and B5 paints, see Figures 5.24 and 5.25. However, the paint films contained a few holes.

Considering the appearance of the dry paint, the B6 monobinder paints had low gloss, see Figure 5.27f. The gray paints exhibited lower gloss than the black paints, and *Gray B6 30%* displayed the lowest with a gloss value of 2 GU. The low gloss values obtained on the boards were a desirable property for the paints produced by Sioo Wood Protection. Furthermore, on leneta paper the B6 paints displayed quite high gloss. Especially the black paints exhibited high gloss around 60 GU, see Figure 5.29f. The holes in the paint film on leneta paper could have affected the gloss values and therefore giving high values.

Regarding the color of the wet B6 paints, the gray paints were similar in lightness and were average compared to the other monobinder paints. For the black paints, *Black B6 30%* was slightly lighter than *Black B6 20%*. In Figures 5.18 and 5.20 it can be seen that the wet paints generally were lighter than the dry paints. Noteworthy is that *Gray B6 20%* had quite similar lightness as wet and dry paint.
Furthermore, the durability of the paints during the weathering test was quite good aside from that the paints had started to peel off at the growth rings. The cross hatch test exhibited quite poor adhesion of the B6 paints. *Gray B6 20%* was ranked

a 4, while the rest of the paints were classified as 5:s, see Table 5.5. Lastly, the solid content for the B6 monobinder paints were lower compared to the other monobinder paints. The paints with PVC 20% had a solid content of 18% and 20%, while the paints with PVC 30% had a solid content of 15% and 16%. Generally, the black paints had higher solid content than the gray paints.

To sum up, the monobinder paints with B6 were produced in a lower volume of 200 ml compared to the other monobinder paints. This could have affected the results and was taken into consideration when choosing the binders to proceed with in the polybinder paints. Moreover, the B6 paints exhibited good stability as wet paints and had good durability in the weathering test. However, the B6 paints had started to peel off at the growth rings. One advantage with the B6 paints was the low gloss on the boards which is a desirable property for the paints produced by Sioo Wood Protection.

6.2.8 General Behaviors of the Monobinder Paints

Several paints produced foam during the formulation of the paints. In these cases a defoamer could be needed. The amount of foaming could be dependent on the amount of surfactants in the binders or the mixing speed. Monobinder paints which contained B2, B3 or B4 had lower amount of foam than the other monobinders paints. Hence, these binders may have contained a lower amount of surfactants or had lower mixing speed.

The evaluation of possible phase separation in the black monobinder paints were difficult because contrary to the other colors, the black paints contained solely one type of pigment. The yellow stability tests had separation of dark and light yellow pigments, and the gray stability tests had separation of black and white pigments. The separation was probably due to flocculation or agglomeration of pigments, the pigments must be evenly distributed to provide a homogeneous color, see Section 2.3. Furthermore, there was phase separation in one of the stability test with binder B2 and gelation in all tests with binder B4. Binder B4 contains a coupling agent, this can explain the gelation in paints with binder B4. A coupling agent can chemically crosslink and thus, create a three dimensional network in the paint, see Section 2.2. Consequently, gelation in the paint is formed due to crosslinking. The paints without coupling agent will not be able to crosslink and thus, no gelation will be formed. Hence, it is more probable that the phase separation in the B2 monobinder paints, which does not contain coupling agent, was creaming, however this was not investigated further since the behavior was only noted for one of the B2 monobinder paints. Moreover, the monobinder paints which had the least phase separation and were the most homogeneous in color contained binders B3, B5 or B6. Out of binder B3, B5 and B6, only B3 contained a coupling agent. Consequently, the stability of the B3 monobinder paints was unexpected.

A general result was that the yellow paints had lower viscosity. Furthermore, this was also noticed when the paints were applied on the boards. The yellow paints were more runny, the paints did not stick to the substrates that well and dripped down from the leneta paper and from the boards. Furthermore, the brush strokes could later be seen in the dried coating which is unexpected because low viscosity usually result in good leveling. Another general result was that paints with PVC 30% displayed lower viscosity than PVC 20%. Paints with PVC 20% contained more binder and can therefore be expected to display a higher viscosity. One exception was observed for paints with binder B1 where the opposite correlation was observed. The opposite correlation could, however, be explained by the result from the stability tests. The test showed that yellow and gray B1 paints with PVC 20% had separated more than the paints with PVC 30%, see Figure 5.1. Hence, the binder may have sedimented more in the paints with PVC 20% than 30% which will lead to lower viscosity. Considering the viscosity of all monobinder paints, paints with binder B2 had the highest viscosity, probably because the binder contains fully reacted siloxane, in other words, polymers with high molecular weight. Whereas, the paints with binder B1 had lowest viscosity, probably because the binder contains lower molecular weight polymers.

The monobinder paints that formed the smoothest films on leneta paper were monobinder paints containing B5, B6 or the acrylate binder, see Section 5.1.6. The film appearance on leneta paper could perhaps be affected by viscosity, for example *Yellow B1 20%* displayed a saggy film in Figure 5.21a. As previously mention, B1 monobinder paints were generally low viscous and especially the B1 monobinder paints with PVC 20%. Moreover, monobinder paint, *Gray B4 30%* also gave a saggy film, displayed in Figure 5.23b. Although, the B4 monobinder paints were generally high viscous. In this case, the saggy film was not due to low viscosity but due to sticky lumps in the paint. The B6 monobinder paints were also low viscous but did not produce a saggy film. The reason could be that B6 monobinder paint generally had a slightly higher viscosity than B1 monobinder paints or that they had higher adhesion to the leneta paper. Another explanation is the type of silicon content present in the binders, paints containing a binder with fully reacted siloxane generally displayed smoother films than binders with silane and polymeric siloxane with coupling agent. The acrylate monobinder paint also formed smooth films, as previously mentioned. The fully reacted siloxane are similar to the acrylate polymer because the polymers are both non-reactive, hence, will not crosslink during drying. Consequently, the result implies that paints which dry through physical drying, not through chemical curing, form smoother films on leneta paper. The exception to this pattern, is paint films of B2 monobinder paints which created a film with holes, possibly fisheyes, see Figure 5.22. However, the film could be smooth if a surface tension decreasing element, polymer or surfactant, is added.

The lightness of wet paint for different monobinder paints were measured, both as wet and dry paint. The blueness, yellowness, greenness and redness were also measured. However, the values were determined irrelevant. The only monobinder paints which gave significant values were the yellow paints and, as predicted, they gave indication of yellowness and some redness. However, there was not a significant difference in lightness between different monobiner paints of the same color.

Further, only the yellow paints showed some correlation to PVC, where lower PVC gave lighter monobinder paints, except for paints with acrylate binder where the two paints with different PVC were equally light. Furthermore, the gray and black paints got darker during drying whereas, the yellow paints got lighter.

Generally, all monobinders had low gloss on the planed boards. Gloss mean values for B1, B2, B3, B4 and B6 monobinder paints were close to the reference gloss value of 4 GU, see Table 3.1. Note, the reference value was for two layers of Wood Protection and one layer of Surface Protection which Sioo Wood Protection currently produces. The B5 monobinders paints and acrylate monobinder paints had a much higher gloss mean value of 11 and 13 GU, respectively, see Table 5.3. In fact, Yellow Acrylate 20% had as much as 25 GU in gloss, see Figure 5.27. Consequently, binder B5 and acrylate binder may provide more gloss to paints.

Generally, monobinder paints of the same PVC varied in solid content, see Table 5.4. The result could imply that slightly different amounts of binder and pigment have been added to every paint with the same PVC, even though the intent was to have the same amount. This may effect the other results since paint properties, e.g. film durability and color, depend on the amount of solid content, see Section 2.4. The deviating solid content could be due to errors during production, see Section 6.5. Furthermore, all monobinder paints with PVC 20% had higher solid content than monobinder paints with PVC 30%. The result is expected, paints with PVC 20% contained higher amount of binder content than paints with PVC 30%.

In regards to durability of the monobinder paints, the best classification, 0, was not obtained for any of the paints in the cross hatch testing, see 5.30. However, the acrylate monobinder paints obtained the best results compared to the other monobinder paints. Five out of six acrylate monobinder paints got the next best classification, 1, which represents good adhesion to the board. The B5 monobinder paints obtained the worst classification, a 5, which represents very low adhesion to the board. The cross hatch test was performed indoors, hence the result gives an indication of the durability without influence of weather. To consider influence of weather, the weathering test was conducted. The result showed that the B4 and acrylate monobinder paints had low durability on the boards in the weathering test. However, the acrylate monobinder paints had good durability in the cross hatch test, as previously mentioned, which indicates that the acrylate monobinder paints are not resistant to weather. The acrylate binder could perhaps be too stiff to endure the shrinking and swelling of wood caused by weather. Although, one must consider the anisotropic property of the boards as well, see Section 6.5. Concerning the B4 monobinder paints, the paints had poor performance in the cross hatch test as well, hence, the B4 monobinder paints had low adhesion both indoors and outdoors. The monobinder paints with the highest durability in the weathering test were paints with binder B1 and B3. Furthermore, monobinder paints with binder B2, B5 and B6 displayed fairly good results in the weathering test, but slightly lower than monobinder paints with B1 or B3, see Section 5.1.11.

Lastly, binders B2, B5 and B6 were selected for testing as polybinder paints, whereas binders B1, B3 and B4 were not. The selection was made due to the undesirable result of monobinder paints with binders B1 and B4. The B1 monobinder paints had good durability in the weathering test, however low stability as wet paints. Furthermore, B4 gave poor adhesion durability both indoors and outdoors. The reason for the unwanted results was considered to be the coupling agents in binder B1 and B4. Even though no unwanted results had been observed for binder B3 at the time of the selection, the binder was not proceeded with, as it contained coupling. The time limit to evaluate the results from the testing of monobinder paints and to select binders to proceed with in production of polybinder paints, was rather short, and for this reason, it was assumed that binder B3 would give equally unwanted results as B1 and B4, with time. The decision was made in discussion and in consensus with Sioo Wood Protection. Although, seen in retrospect, the initial beneficial results of binder B3 remained and persisted, both in the wet paint and in the weathering. Binder B3 could therefore be a relevant candidate for Sioo Wood Protection to consider. However, the results from the weathering test and stability test would need further evaluation.

6.3 Polybinder Paints

This section contains a summary of the results for each polybinder paint, see Sections 6.3.1, 6.3.2, 6.3.3 and 6.3.4. In Section 6.3.5, the results from the testing of the polybinder paints will be discussed more thoroughly and will be compared with the results from the testing of monobinder paints. For short information about each binder, including physical data and observations during the project, see Appendix A.

6.3.1 Poly-Acrylate-Ref

The polybinder paint, *Poly-Acrylate-Ref* had the second highest foam decrease of 22.73% compared to the other polybinder paints. An expected behaviour due to the foam decrease seen for the monobinder paints with acrylate. Furthermore, the viscosity was the second lowest of all polybinder paints. Although low viscosity, the paint was easy to apply on the boards. The paint was not as runny as the monobinder paints with acrylate and appeared to provide good coverage. The same similarity in behavior as the monobinder paints was noticed during application on leneta paper, where the film formed a smooth paint film. However, the film included some areas without paint, see Figure 5.44a.

The appearance of *Poly-Acrylate-Ref* was low in lightness both as wet paint and dry paint. The paint was the second darkest wet polybinder paint of all polybinder paints and the darkest dry polybinder paint. The result was similar to the result of the wet acrylate monobinder paints which were amongst the darkest. However, the dry monobinder paints with acrylate were among the lightest monobinder paints. Similarly as with the monobinders with acrylate, *Poly-Acrylate-Ref* had phase separated the most of all polybinder paints and had a wide layer of dark paint separated at the surface. Regarding gloss, the paint was the third glossiest polybinder paint both on leneta paper and boards. An undesired property for the paints produced by Sioo Wood Protection. The paint had the second highest solid content, the same content as *Poly-B2-M*.

Regarding the durability of the dry paint, *Poly-Acrylate-Ref* received the best result in the cross hatch testing. *Poly-Acrylate-Ref* was the only paint which was ranked a 1. However, the paint did not have as good performance in the weathering test where an extensive amount of the paint coating peeled off along the earlywood and partly along the latewood. The result is unexpected since paint tend to detach on latewood before earlywood due to higher density. High density wood swells and shrinks more than lower density wood. An explanation to the opposite result could be the surface texture of the board. If the earlywood had a smoother surface than the latewood, the paint could have detached faster on earlywood since coating performance also depends on surface texture. However, latewood is usually smoother than earlyood, hence there could be an other reason. Furthermore, the result from the accelerated weathering test implied average durability for *Poly-Acrylate-Ref* on the board compared to the other polybinder paints.

To sum up, compared to the monobinder paints with acrylate, *Poly-Acrylate-Ref* was easier to handle despite low viscosity. The paint was quite dark both as wet and dry paint compared to the other polybinder paints. Furthermore, the paint had high gloss on leneta paper and on the boards compared to the other polybinder paints. The durability as dry paint was best in cross hatch testing. However, only average in accelerated weathering test and poorly in the weathering test.

6.3.2 Poly-B2-M and Poly-B2-H

The polybinder paints with binder B2 exhibited quite high viscosity, *Poly-B2-M* displayed the third highest while *Poly-B2-H* displayed the highest, see Figure 5.39. Consequently, higher B2 content gave higher viscosity. This corresponds to the B2 monobinder paints where the same behaviour could be seen. The B2 monobinder paints exhibited the highest viscosity out of the monobinder paints, see Figure 5.8a. Hence, it was expect to see the same behaviour for the polybinder paints. Moreover, the B2 polybinder paints were easy to apply on the boards and both paints exhibited high coverage. Furthermore, *Poly-B2-M* contained a lot of foam and had the third highest foam decrease. Contrariwise, *Poly-B2-H* contained a low level of foam and was the paint which had the lowest foam decrease. The B2 monobinder paints displayed the same behaviour as *Poly-B2-H* with a low foam decrease, consequently this was an expected result. However, for *Poly-B2-M* the high foam content could be due to the acrylate content in the paint. For the monobinder paints, the acrylate paints had higher foam decrease than the B2 paints, see Table 5.2. Consequently, it is logical that *Poly-B2-M* would have a high foam decrease. Furthermore, *Poly-B2-H* displayed high stability as wet paint and in the stability test, no phase separation could be seen. In fact, *Poly-B2-H* displayed the most stable paint out of all polybinder paints, see Figure 5.38. This complies with the B2 monobinder paints, see

Figure 5.2. However, *Poly-B2-M* did not display the same stability as wet paint. In the stability test, white dots could be seen and the paint had also started to phase separate, see Figure 5.38. Nevertheless, the B2 polybinder paints created an even paint film on the leneta paper. Similar as for the B2 monobinder paints, small holes could be seen in the paint film for both *Poly-B2-M* and *Poly-B2-H*, see Figure 5.43. The same assumption as for the B2 monobinder paints applies here, these holes could possibly be fisheyes.

Considering the appearance of the dry paint, the B2 polybinder paints typically had low gloss on boards, see Figure 5.46. On leneta paper, the B2 polybinder paints exhibited higher gloss than on wood. However, *Poly-B2-M* and *Poly-B2-H* displayed the lowest gloss out of all polybinder paints. Note, as previously mentioned there were possible fisheyes in the film which could have affected the measurement of gloss. Although, the low gloss complies with the result for the B2 monobinder paints which displayed low gloss, see Figure 5.29b.

Regarding color of the wet B2 polybinder paints, both paints were the lightest out of all polybinder paints, see Figure 5.40. For the color of the dry paints the B2 exhibited average lightness compared to the other polybinder paints, see Figure 5.41. Furthermore, the durability of the B2 polybinder paints during the weathering test on planed boards was quite good. *Poly-B2-M* had peeled off evenly over the whole board, while *Poly-B2-H* had peeled off unevenly. Particularly in the top left corner the paint had peeled off extensively, see Figure 5.52. In the cross hatch test, *Poly-B2-M* was classified as a 2 and *Poly-B2-H* was classified as a 5, see Table 5.8. The classification for *Poly-B2-M* corresponds with the result for the weathering test. Furthermore, in the QUV accelerated weathering test the B2 polybinder paints displayed quite average durability after 150 h compared to the other paints. After 300 h, the B2 polybinder paints on the other hand exhibited very good durability on the board. However, for the QUV weathering test after 500 h the obtained result displayed varying durability for the B2 polybinder paints. For *Poly-B2-M*, the durability of the paint was very good and the paint was classified with a 1. However, for *Poly-B2-H*, the durability was poor and the paint was classified with a 7, see Table 5.57.

To summerize, the B2 polybinder paints exhibited good stability as wet paints. Especially for *Poly-B2-H* which had a homogeneous color and did not exhibit any phase separation. Moreover, the B2 polybinder paints also displayed quite good durability in the weathering test and the QUV weathering test. Particularly, *Poly-B2-M* had good durability on the board after 500 h in the QUV and was ranked number 1 out of all polybinder paints. A general appearance which could be seen in the dry paint film on leneta paper was small holes. The same behaviour was seen for B2 monobinder paints.

6.3.3 Poly-B5-M and Poly-B5-H

Polybinder paint, *Poly-B5-H* had the highest foam decrease of all polybinder paints with 27.27%. The result agreed with the foam decrease of the gray B5 monobinder paints which also exhibited high foam decrease. However, when acrylate and Bx were added the amount of foam decreased. Polybinder paint, *Poly-B5-M*, only had a foam decrease of 19.05%. Although, still quite high foam decrease, it was the third highest foam decrease of all polybinder paints. Furthermore, the gray monobinder paints with acrylate contained a high foam content as well, 29.59% for PVC 20% and 17.48% for PVC 30%. Hence, the high foam content in the polybinder paints with binder B5 is not unexpected. Moreover, *Poly-B5-H* had the next highest viscosity of all polybinder paints. Whereas, *Poly-B5-M* had under average viscosity compared to all polybinder paints.

Furthermore, in the stability test for *Poly-B5-M*, a white layer had formed at the surface. The white layer at the surface stood out from most other stability tests, monobinder paints included, since white pigment tended to form a sediment at the bottom of the cup. Consequently, the white layer could perhaps be content from the white binders in the paint which have separated to the surface. From visual observations at the company, there is a suspicion that the content comes from the acrylate binder. However, it is odd that the same behavior is not observed in the stability test from *Poly-Acrylate-Ref*, where instead black pigment had separated to the surface. Moreover, the bulk layer of the stability test of *Poly-B5-M* had a homogeneous color. Regarding the stability test of *Poly-B5-H*, the test had no phase separation, although some small, air bubbles were present in the bulk. Otherwise, the test was homogeneous. It can be concluded that the B5 polybinder paints exhibited better stability when all acrylate had been substituted.

Considering durability of the B5 polybinder paints, both paints exhibited low adhesion in the cross hatch test. The paint containing acrylate, *Poly-B5-M*, had slightly better durability but was still classified as a 4. The result from cross hatch testing complies with the result from the weathering test. *Poly-B5-M* peeled of a lot just after one week and had lower adhesion ability and durability on the planed boards compared to *Poly-Acrylate-Ref*. *Poly-B5-H* had even lower durability and adhesion strength, in the final result almost all paint had peeled off. For the monobinders, paints with binder B5 obtained the highest marking whereas paints with acrylate got the lowest marking. Hence, the behavior of the B5 polybinder paints complies with previous result from cross hatching testing. However, the B5 monobinder paints exhibited good adhesion and durability in the weathering test, even better durability than the monobinder reference paint with acrylate which was a reason for selecting binder B5 for polybinder paints. Hence, the addition of Bx with binder B5 could have had an effect. Better results were seen for *Poly-B5-M*, the reason could be that the binders, acrylate and Bx, are more compatible, which previous results imply. Yet, the accelerated weathering test indicated high durability for *Poly-B5-M*. However, the result from *Poly-B5-H* complied with the result from the other durability tests. Both B5 paints had high durability after 150 h compared to the other polybinder paints, however the B5 polybinder paints were among the polybinder paints with lowest durability after 300 h. Although, the final result after 500 h ranked *Poly-B5-M* as the polybinder paint with the next highest durability whereas *Poly-B5-H* was marked as having the second lowest durability. Noteworthy, the accelerated weathering test was performed on fine sawn boards. Hence, the *Poly-B5-M* may have higher durability on fine sawn boards compared to the other polybinder paints. Another explanation is that the accelerated weathering test cannot completely simulate reality, there will always be errors.

Concerning appearance of the B5 polybinder paints, there was a suspicion that the paints might have high gloss due to the results obtained for the monobinder paints. Monobinder paints with B5 or acrylate generally had the highest amount of gloss on the boards, see Table 5.3, and high gloss on leneta paper, see Figure 5.29. The suspicion got confirmed, *Poly-B5-M* had the highest gloss of all polybinder paints on both leneta paper and on the boards. Furthermore, *Poly-B5-H* had the second highest gloss on both leneta paper and on the boards. The paint with acrylate was probably glossier because the acrylate binder gave slightly higher gloss than binder B5 which was observed for the monobinder paints.

In summary, observations from the stability test of the B5 polybinder paints indicated that adding acrylate resulted in phase separation of the wet paint. Hence, for B5 polybinder paints, a better stability is obtained when all acrylate has been substituted. Furthermore, the paints were quite easy to handle due to high viscosity. Regarding durability of the B5 polybinder paints on boards, the paints received an overall low durability. The strongest indicator for low durability was that all coating, from the two polybinder paints, peeled off from the planed wood in the weathering test. Regarding the appearance of the B5 polybinder paints, gloss was high for both polybinder paints. Consequently, gloss may have to be compensated for if binder B5 should partially or completely substitute acrylate. Furthermore, a conclusion that binder B5 may provide lightness to the paints and acrylate may provide darkness can also be made based on the results from the polybinder paints and the monobinder paints.

6.3.4 Poly-B6-M and Poly-B6-H

For the B6 polybinder paints a smaller volume was produced compared to the rest of the polybinder paints, see section 4.2.2. Consequently, the B6 polybinder paints were produced under different conditions compared to the rest of the polybinder paints. This could affect the results obtained for the B6 polybinder paints and was taken into consideration when evaluating the results.

Poly-B6-M had the lowest foam decrease of all polybinder paints with 8.42%, while *Poly-B6-H* had the third lowest foam decrease with 15.79%, see Table 5.6. This contradicts the result for the monobinder paints which had the third highest foam decrease, see Table 5.2. Moreover, the B6 polybinder paints had low viscosity and *Poly-B6-M* had the second lowest viscosity of all polybinder paints, see Figure 5.39. The B6 monobinder paints exhibited low viscosity, see Figure 5.10. Hence, it was expected to see the same behaviour for the B6 polybinder paints. Moreover, the B6 polybinder paints were easy to apply on the board, but *Poly-B6-M* was a bit runny because the paint had low viscosity. Furthermore, in the stability test *Poly-B6-M* had phase separation. There was a lighter layer at the surface, see Figure 5.38. Contrariwise, the B6 monobinder paints had a homogeneous color and had no phase separation, see section 5.1.1. Consequently, the lighter layer at the surface could be due to the acrylate or Bx in the paint. The same assumption could be made here as for *Poly-B5-M* that the white content comes from the acrylate, see section 6.3.3. For *Poly-B6-H* there was no phase separation detected, however at the surface there was a transparent layer with a gray circle. Furthermore, the B6 polybinder paints did not create a homogeneous paint film on the leneta paper. There were several sections in the paint film where there was no paint. *Poly-B6-M* had bigger sections where paint was missing compared to *Poly-B6-H*. Due to this the gloss values taken on the leneta paper could be inaccurate.

Considering the appearance of the dry paint, the B6 polybinder paints typically had low gloss on boards where *Poly-B6-H* had the lowest gloss of all polybinder paints with a gloss value of 2.5 GU. For *Poly-B6-M*, the gloss value was a slightly higher with 4.7 GU. The low gloss complies with the result for the B6 monobinder paints which displayed low gloss on boards, see Figure 5.27f. On leneta paper, the B6 polybinder paints exhibited higher gloss than on wood. However, compared to the acrylate and B5 polybinder paints the gloss of the B6 polybinder paints were quite low. Neither of the B6 polybinder paint had a gloss value above 15 GU.

Regarding color of the wet B6 polybinder paints, *Poly-B6-M* was the darkest paint out of all polybinder paints and *Poly-B6-H* was average compared to the other polybinder paints, see Figure 5.40. For the color of the dry paints, the B6 polybinder paints had quite high lightness compared to the other polybinder paints, see Figure 5.41. *Poly-B6-H* exhibited the highest lightness. However, the dry paints were lighter than the wet paints, see Figure 5.42. Noteworthy was that *Poly-B6-M* displayed the opposite correlation where the dry paint was a slightly lighter than the wet paint. By comparing the the dry paint with the wet paint for *Poly-B6-M*, it could be concluded that the lightness of the paint was very similar, see Figure 5.42. Consequently, this makes it easier to correlate the wet paint with finished result during production.

Furthermore, the durability of the B6 polybinder paints during the weathering test on planed boards was quite good. For *Poly-B6-M*, the paint had peeled off with the growth rings. Noteworthy was that the paint had seemed to peel off at the earlywood. For *Poly-B6-H*, flaking could be seen before the paint fell off. The paint had mainly peeled off at the right part of the board. Compared to *Poly-B6-M* the paint had peeled off at the latewood. In the cross hatch test, *Poly-B6-M* was classified as a 2 and *Poly-B6-H* was classified as a 4, see Table 5.8. The classification for *Poly-B6-M* corresponds with the weathering test where the paint displayed good durability. Furthermore, in the QUV accelerated weathering test *Poly-B6-M* displayed quite good results. After 150 h in the QUV the paint was ranked a 1, representing best durability. No paint had peeled off on the board. However, for *Poly-B6-H* a different result was displayed. This paint had two section in the middle of the board where a lot of the paint had peeled off and therefore it was ranked with a 7, representing the worst durability, see Table 5.55. After 300 h, *Poly-B6-H* still demonstrated a poor durability and was also here ranked with a 7. The same area in the middle of the board where the paint had peeled off extensively could also be seen here. For *Poly-B6-M*, better durability was demonstrated and the paint was ranked a 3, see Table 5.10. Further, for the QUV weathering test, after 500 h, both B6 polybinder paints demonstrated average durability. *Poly-B6-M* was ranked a 4 and *Poly-B6-H* was ranked a 5. *Poly-B6-M* peeled off at growth rings and a knot. Similarly, *Poly-B6-H* had peeled off at a knot.

To summarize, the B6 polybinder paints were produced in a smaller volume compared to the rest of the polybinder paints. This was taken into consideration when comparing the results of the polybinder paints. The B6 polybinder paints demonstrated low foam content and *Poly-B6-M* had the lowest foam decrease of all polybinder paints. Both of the B6 polybinder paints exhibited low viscosity. Regarding the durability of the paints in the weathering test and QUV accelerated weathering test, the B6 polybinder paints exhibited quite varying results. In the weathering test, the paints demonstrated quite good durability. However, in the QUV, *Poly-B6-H* displayed poor durability after 150 h and 300 h and was ranked with a 7 in both cases. *Poly-B6-M* displayed good durability after 150 h but had an average durability after 300 h and 500 h.

6.3.5 General Behaviors of the Polybinder Paints

For the polybinder paints, varying results were obtained for the foam stability test, see Table 5.6. No correlation was observed between the polybinder paints with acrylate and the polybinder paints without acrylate. Consequently, the foam content seemed to depend on mixing velocity rather than acrylate content in the paints. Considering viscosity, all polybinder paints were shear thinning which is a beneficial property of paints because it facilitates the application of paint, see Figure 5.39. Further, in Section 6.2, it was stated that the application was more difficult when the monobinder paints had low viscosity. However, all polybinder paints were quite easy to apply, independent of viscosity. The reference paint, *Poly-Acrylate-Ref* had the lowest dynamic viscosity of all polybinder paints but was still easy to apply and was not runny. Consequently, all polybinder paints had workable viscosities.

A general result from the stability tests was that a white layer formed at the surface for polybinder paints containing a combination of acrylate binder and one of the investigated binders, B2, B5 or B6, in other words, for *Poly-B2-M*, *Poly-B5-M* and *Poly-B6-M*. There is a suspicion at the company, based on visual observation, that the solvent in the acrylate binder tends to phase separate to the surface. Although, contradictory, the reference paint with solely acrylate and Bx, *Poly-Acrylate-Ref*, did not show this pattern. In that case, dark pigment had instead formed a layer at the surface. Hence, the combination of one of the investigated binders and acrylate could have cause the white layer, or the specific concentration of acrylate in those cases. Further investigation has to be done to determine the reason. The polybinder paints, *Poly-B2-H* and *Poly-B5-H* were the only polybinder paints that had no phase separation. Furthermore, *Poly-B2-H* had the most homogeneous color of the two and had no dispersed air bubbles like *Poly-B5-H*. Moreover, the reference paint *Poly-Acrylate-Ref* had separated the most. Hence, by not including acrylate in the polybinder paints, more stable wet paints were obtained, where *Poly-B2-H* and *Poly-B5-H* were the most stable paints.

Generally, the polybinder paints had similar solid content approximately 22%, except *Poly-B6-H* which only had a solid content of 15%, see Table 5.7. The result is an indication that approximately the same amounts of binder and pigment have been added to every polybinder paint. This strengthens the credibility of the other results because lower/higher amount of solid content could otherwise affect the comparison of result from different binders. The reason why the solid content was inconsistent, is probably due to possible errors during production, see Section 6.5.

Regarding appearance, all polybinder paints without acrylate tended to be matter on leneta paper and on the planed boards than the polybinder paints with acrylate, see Figure 5.47 and Figure 5.46. Consequently, the acrylate binder appear to contribute with gloss to paints. Further, adding binder B5 to the paint resulted in higher gloss for the polybinder paints on leneta paper and on planed boards compared to the other investigated binders. Moreover, a combination with binder B2 resulted in paints with lower gloss on leneta paper and planed boards compared to the other polybinder paints. The result complies with results from monobinder paints. Furthermore, the lightness of the polybinder paints generally got darker when dried on the planed boards. The result could be expected since solvent evaporates and the pigments get more concentrated on the board. Additionally, the darkness of the board in itself could probably also contribute. However, *Poly-B6-M* had a similar lightness both as wet and dry paint, see Figure 5.40. Similarly, *Poly-B6-H* had a small change in lightness when dried. Consequently, it could be easier to correlate lightness for the wet paint with finished result during production. The B2 polybinder paints were the lightest wet paints and had the largest change in lightness when dried. However, the change was only three units. The B2 binder had a relatively large change in lightness for the monobinder paints as well, as observed in Section 6.2, at least compared to the other monobinder paints. Consequently, it could be slightly harder to correlate lightness for the wet paint with finished result during production for paints containing B2. However, further testing have to be made to determine this, other factors could influence the lightness e.g. solid content.

Interestingly, the B2 polybinder films on leneta paper displayed the same type of holes as for the B2 monobinder paints, see Figure 5.43. This strengthens that binder B2 could contain lower amount of surface tension decreasing polymers. The B5 and B6 polybinder paints formed similar smooth films as the reference paint, *Poly-Acrylate-Ref*, however, the films from the B6 polybinder paints contained more holes without paint. Consequently, B5 polybinder paints formed the best films on leneta paper out of polybinder paints with the investigated binders. Furthermore, if binder B2 is used in polybinder paints, a surface tension decreasing element could be needed in order to form smooth films.

Regarding durability and adhesion strength on the boards, polybinder paints with binder B2 or B6 had the best results in the weathering test. Polybinder paints with binder B2 had slightly better results than polybinder paints with binder B6. However, polybinder paints with binder B5 gave the worst result because almost all coating peeled of in the end. Furthermore, the acrylate reference polybinder paint had better durability than the B5 polybinder paints. However, lower durability than polybinder paints with binder, B2 or B6. Hence, binder B2 and B6 could be more beneficial substitutes to partially replace the acrylate in this case. The result from the accelerated weathering test after 500 h, showed best results for all paints that contained acrylate, *Poly-Acrylate-Ref* included, see Table 5.11. The polybinder paints, *Poly-B2-M* and *Poly-B5-M* gave better performance than the reference paint, *Poly-Acrylate-Ref*, while *Poly-B6-M* gave lower performance. The polybinder paint with lowest performance was polybinder paint, *Poly-B2-H*.

Furthermore, cross hatch testing generally gave better results for the polybinder paints with acrylate, where the acrylate reference paint got the best classification. In fact, the acrylate reference paint was the only polybinder paint which was classified as a 1. The paints without acrylate got classified with a 4 or 5 which indicates that almost all paint got removed during the testing. However, slightly less amount of coating peeled off for *Poly-B6-H* than for *Poly-B2-H* and *Poly-B5-H*. Polybinder paints, *Poly-B2-M* and *Poly-B6-M* were second best to the reference polybinder paint in cross-hatch testing and were amongst the polybinder paints which received the highest scoring in the weathering test also, as previously mentioned. However, *Poly-B6-H* and *Poly-B2-H* also received the highest scoring in the weathering test which contradicts the cross hatch test, this could be because the boards had not been exposed to weather during the cross hatch test, e.g. swelling and shrinkage of the wood. As previously mention, the acrylate binder could be too stiff to manage shrinking and swelling of the wood and therefore performed worse than paints without acrylate, see Sections 2.5 and 2.8.1. Furthermore, in the accelerated weathering test, fine sawn boards were used. In the cross hatch testing, only planed wood was used. Hence, the type of board could have influenced the result.

6.4 Environmental Assessment

In this section the results from the environmental assessment will be discussed for both the monobinder paints and the polybinder paints. The environmental assessment includes manufacture and transportation of the binders. The impact of each binder is independent of color, hence the paints will be named after type of binder and PVC in Section 6.4.1, for example *B2-20%* will refer to all monobinder paints containing binder B2 with PVC 20%.

6.4.1 Monobinder Paints

For the manufacture of the monobinder paints, *B5 20%* displayed the highest impact, while *B6 30%* displayed the lowest, see Figure 5.58. Generally paints with PVC 20% exhibited a higher impact compared to the paints with PVC 30%, an expected result since the paints with PVC 20% contained a higher amount of binder. Noteworthy was that *B5 30%* displayed a higher impact than several of the paints with PVC 20%, and *B6 20%* displayed a lower impact than several of the paints with PVC 30%. The conclusion could be made that binder B5 may not be a desirable alternative to use due to the high impact.

For the current transportation of the binders, both *B6 20%* and *B6 30%* displayed the highest impact, see Figure 5.59a. This was due to the current transportation of the binder with aircraft. However, if Sioo Wood Protection decides to incorporate binder B6 in their production, a larger quantity would be purchased and consequently the binder would be transported by ship. This would lower the impact of transportation significantly which could be seen in Figure 5.59b. In fact, both *B6 20%* and *B6 30%* would then display the lowest impact, while *Acrylate 20%* and *B5 20%* would display the highest. This strengthens the choice to incorporate binder B6 in the product. Binder B6 had low impact both in the manufacture step and the transportation step. Moreover, binder B5 displayed high impact from both manufacture and transportation, and would therefore not be considered a good option.

6.4.2 Polybinder Paints

For the polybinder paints, the same correlation could be seen for the impact from manufacture and transportation as for the monobinder paints, see Section 6.4.1. The paints with binder B5 displayed the highest impact during manufacture, while the paints with binder B6 displayed the lowest. As mentioned in the result, the impact increased when all acrylate had been substituted with one of the selected binders. The conclusion could be made that for paints containing binder B5 and B2 it is beneficial to substitute all acrylate. However, for the paints with binder B6 the opposite was noticed. In this case, the impact increased when not all acrylate had been substituted with B6. Hence, it is more beneficial to substitute all acrylate with binder B6.

For the current transportation, the paints with binder B6 exhibited the highest impact, see Figure 5.61a. As mentioned for the monobinder paints, this was due to transportation with aircraft. However, if Sioo Wood Protection would incorporate binder B6 in the production the impact would decrease. Consequently, the polybinder with binder B6 would exhibit the lowest impact, while the reference paint with acrylate would display the highest, see Figure 5.61b. Generally, it could be seen that the impact decreased when the acrylate had been substituted with one of the selected binders. Consequently, it is more beneficial to substitute all acrylate with one of the selected binder, where binder B6 is the most beneficial alternative.

In conclusion, binder B5 displayed high impact from both manufacture and transportation for the monobinder paints and polybinder paints, and would therefore not be considered a good option. Binder B2 displayed average impact compared to the binder B5 and B6, and could be an option. However, if binder B6 is transported by ship, it display the lowest impact from both manufacture and transportation. Binder B6 would consequently be considered the most suitable choice. Furthermore, the paints exhibited the lowest impact when all acrylate had been substituted with binder B6.

6.5 Possible Errors

This project includes several sources of error, both from the production and testing of the paints. During the production, factors such as measurement accuracy, rate of addition of ingredients, and velocity of mixing could have impacted the obtained properties of the paints. Due to varying viscosities of the binders, the paints required different mixing velocities during paint production to obtain a vortex. Too low velocity during mixing could result in poor mixing of ingredients. Additionally, the accuracy of measurement when measuring the amount of different ingredients could affect the ratio of ingredients in the paints. Depending on the accuracy, different paints could have had different ratios, thus giving different properties to the final paint. Furthermore, a few ingredients could be mixed in advance before producing the whole paints. These prepared solutions had to be reproduced several times when consumed during the project time. Hence, depending on measurement accuracy these formulations could have had different ingredient ratios, thus giving different ratios to final paints. This could affect e.g the color of the paints.

During the testing of paints, several test methods had many sources of error. One larger error could be the gloss measurements on leneta paper since many of the paints created patchy paint films, see Section 5.1.6. This could have been caused by too low amount of paint in the applicator. A few paints were very low in viscosity and therefore more paint had to be added to the applicator to make sure that the paint would last during the whole application. To sum up, the quality of the paint film could have affected the gloss measurements presented in Figure 5.29.

The leneta paper was used because it is an isotropic material which will give more equal condition for each testing. The board, on the other hand, is an anisotropic material. Properties of wood will be dependent on measurement area, e.g. knots and annual rings could affect the result. Moreover, the paints generally gave smoother films on the planed boards and thus, the results could be more accurate on planed boards compared to the results obtained on leneta paper. The planed boards with two layers of Wood Protection had a gloss value of approximately 11 GU, whereas the leneta paper had approximately 90 GU. The boards were thus a very matt background and the leneta papers were a very glossy background for the paints. This was also noticed in the result as paints on leneta paper were much glossier than paints on the boards. Hence, the gloss from the leneta paper was most likely visible through the paint film. In conclusion, gloss measurement on wood is more trustworthy in this case. Moreover, as mention before, leneta paper is an isotropic material and could give more equal conditions for testing. Hence, if a homogeneous paint film is formed on leneta paper, the gloss measurements could strengthen the result obtained on the boards, for example, if high gloss is obtained on the boards and the same pattern is seen on leneta paper, the conclusion could be made that the results most likely are accurate and this is a characteristic trait for the specific binder.

6.6 Future Work

In this study the paints were compared by constant PVC, however the solid content varied in the paints. In future studies it could be interesting to instead analyze constant solid content for all manufactured paints, since it is an important factor influencing paint properties. The optimal test conditions would be to have a constant solid content and investigate different PVC's with the same solid content.

Binder B3 was not selected for production of polybinder paints. This decision was mostly based on predicated results and due to the time limit. However, the predicated results appeared to be inaccurate and binder B3 gave good results both as wet and dry paint. The B3 polybinder paints exhibited high stability in the stability test and good durability in the weathering test. Hence, in a future study it could be of interest to investigate binder B3 further. Especially, the stability of the B3 paints would be interesting. Sioo Wood Protection´s Surface Protection in panel paints is supposed to be stable for ca 2 years, hence the paints should be tested for that long. Moreover, due to the time limit, the weathering test was only performed for about two months. During this time no drastic change could be seen in the paint coatings on the fine sawn boards. Consequently, for future investigation, a suggestion could be to perform the weathering test during a longer time period to get a better indication of the durability of the paint coatings. The time limit also restricted the amount of test methods that could be performed. In future studies, properties such as hiding power and sag resistance could be interesting to investigate. Lastly, due to the time limitations, the scope of the analysis was kept small. Hence, a complete LCA study could not be performed, only the first steps e.g. A1 and A2. It would be interesting for a future study to perform a complete LCA study to investigate the total impact of the substitution of acrylate with one of the investigated binders. Moreover, no investigation of propagation of error or the statistical significance of the results was made. In future work, it would be interesting to determine the significance of the results.

7

Conclusion

The results for the testing of monobinder paints showed that all binders which contained fully reacted siloxane (hence, B2, B5 and B6) displayed the most desirable properties of the manufactured paints. These monobinder paints exhibited low phase separation in the stability tests, and had high durability on boards in the weathering test. Other monobinder paints, paints containing binder B1 and B4, did not meet the functional requirements for wet and dry paints. In the stability test, the monobinder paint with binder B1 or B4 demonstrated low storage durability, the paints phase separated or had coalescence after only a few weeks. The phase transformation could be due to the coupling agent present in the binders. Additionally, for monobinder paints with binder B1, the viscosity was very low which complicated the application of the paints on the boards for the weathering test. Apart from binder B2, B5 and B6, binder B3 also displayed good properties in wet and dry paint, and could be an interesting choice to consider for Sioo Wood Protection. However, testing of the monobinder paints containing binder B3 have to be evaluated for a longer time period, to evaluate long-term stability. The binder contains a coupling agent which could potentially lead to instability during storage. Moreover, binder B3 has to be tested in polybinder paints to evaluate the compatibility with binder Bx.

The results for the testing of the polybinder paints containing one of the investigated binders, B2, B5 or B6, showed best results for binders B2 and B6. Polybinder paint *Poly-B2-H* was one of the polybinder paints which had highest stability as wet paint. Further, the B2 polybinder paints had high durability and adhesion strength in most durability tests. However, a surface tension decreasing element may have to be added to avoid fisheyes in the coating. In the accelerated weathering test, *Poly-B2-M* displayed better durability compared to *Poly-B2-H*, hence the conclusion could be made that acrylate should not be completely substituted with binder B2 to obtain desired properties. In addition, *Poly-B2-M* also displayed quite low environmental impact.

The advantages with polybinder paints containing binder B5 were that the paints generally had high stability as wet paints and formed smooth films on leneta paper, similar to films formed by the reference paint with acrylate. However, disadvantages with binder B5 was that the paints exhibited low durability in the weathering test, especially for polybinder paint, *Poly-B5-H* where all paint had peeled off in the end of the test period. After 500 hours in the accelerated weathering test, *Poly-B5-H* showed low durability. However, contradicting the weathering test, polybinder paint

Poly-B5-M displayed one of the highest durabilities. Consequently, a combination of acrylate and binder B5 could be a preferable choice to obtain desirable properties. The environmental assessment showed that the B5 polybinder paints had the highest impact during manufacture, and similar impact of transportation as the acrylate reference paint. Although, considering all results, binder B5 may not be a desirable choice for Sioo Wood Protection to replace the acrylate.

The B6 polybinder paints, on the other hand, could be a desirable alternative for the Surface Protection paint, the performance of these polybinder paints was quite high in most tests. In the weathering test, polybinder paints with binder B6 exhibited high durability, however polybinder paint *Poly-B6-H* displayed the highest. In the accelerated weathering test, both paints containing binder B6 displayed average durability. Furthermore, the paints also exhibited good stability in the stability tests. Considering the environmental impact, the B6 polybinder paints had significantly higher impact in transportation compared to the other polybinder paints. This was due to the current transportation with aircraft. However, if Sioo Wood Protection decides to incorporate the binder in their production, the binder would be transported with ship and consequently give the B6 polybinder paints the lowest impact.

Considering the appearance of all paints, including both monobinder and polybinder paints, they were rather matt. The result was desirable because Sioo Wood Protection´s Surface Protection paint should be matt. Hence, compensation for gloss could be unnecessary. However, one should be aware that binder B5 and acrylate may increase gloss in paints. Concerning lightness/darkness of the paints, binder B5 may provide lightness to the paint and acrylate may provide darkness to the paint. However, the lightness between different paints, including both polybinder and monobinder paints, was not large and could be an irrelevant factor when deciding the optimal binder for paint production at Sioo Wood Protection.

The overall results, both from a functional and environmental perspective, suggest that binder B6 is the most preferable choice to substitute the acrylate and obtain desirable properties with low environmental impact. However, further long-term testing and a complete LCA have to be performed to strengthen the result.

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A

Appendix 1

All binders used in the project will be descried in this appendix. The structure will be as follows;

Binder (Bi): *Here in italic is the known ingredients of the binder. The percentage of the ingredient is presented in parentheses e.g.* ingredient B (50%). *Furthermore, there could be unknown ingredients so the water content is only approximate in this case.*

Physical data:

Table A.1: Physical data for the binder

Active Content [%]	Density [g/cm^3]	Appearance	Hazards
-	-	-	-

Observations during project: Here is some general observation, made during the project, of the binder solely and of the produced paints containing that binder.

Binder B1: *Silane and polymeric siloxanes (53%), silane coupling agent (25%), dodecametylcyclohexasiloxane (1%), unknown content (26%)*

Physical data:

Table A.2: Physical data for binder B1

Active Content [%]	Density [g/cm^3]	Appearance	Hazards
53	1	white	corrosion, causes serious eyedamage and skin irritation

Observations during project: B1 is of low viscosity on its own. The formulated paints from the binder are runny, especially the paints with PVC of 20%, and sometimes there are small lumps in the paint. Generally, during formulation of paints with binder B1, adhesive lumps appeared on the blade of dissolver. In the gray paints, black pigment separates to the surface. Furthermore, the foam in the paint disappears rather quickly, approximately within 3 days.

Binder B2: *Fully reacted siloxane (54%), unknown content (46%)*

Physical data:

Table A.3: Physical data for binder B2

Active Content [%]	**Density** [g/cm^3]	**Appearance**	**Hazards**
50	1	white	not a harzardly substance or mixture

Observations during project: Binder B2 is very viscous and sticky on its own and therefore a bit more tricky to handle than binder B1. However, the formulated paints are more homogeneous e.g. no lumps and are more viscous than the paints formulated with binder B1. Especially the paints with PVC of 20% have better consistence with binder B2 than with binder B1. They are not as runny. The produced paints have a bit foam but not as much as binder B1. Although, the foam seem to be a bit more stable than the foam from paints with binder B1.

Binder B3: *Silanes and polymeric siloxane (54%), Siloxane coupling agent (20%), octamethylcyklotetrasiloxane (1%), unknown content (25%)*

Physical data:

Table A.4: Physical data for binder B3

Active Content [%]	**Density** [g/cm^3]	**Appearance**	**Hazards**
54	1	white	skin and eye irritating, aquatic chronic

Observations during project: The formulated paints with binder B2 were only slightly foamy with few bubbles and no lumps in the paint. Although, the foam was quite stable for the gray and black paints. When no change in amount of foam had been seen for weeks, the foam had to be slowly stirred to disappear. The foam did not return when they were checked the next day. Apart from that, the binder alone and the formulated paints felt low viscous like binder B1 but with more homogeneous color for the gray paints. The paints was believed to be more runny than the paints with binder B2. After approximately two weeks, creaming could be seen in the foam test of the gray paint with PVC of 20%.

Binder B4: *Silanes and polymeric siloxanes (40%), siloxane coupling agent (16%), octamethylcyklotetrasiloxane (1%)*

Physical data:

Table A.5: Physical data for binder B4

Active Content [%]	**Density** [g/cm^3]	**Appearance**	**Hazards**
40	1	white	skin irritating, should not be inhaled

Observations during project: Binder B3 resembles binder B1 in consistency, it is quite runny. Furthermore, it is quite sticky. During the experimental procedure, it attached to lab equipments and to the blade of the dissolver. Even, dish soap did not really remove it. Small sticky lumps were also present in the paints. Consequently, the binder is quite hard to handle. Additionally, there was a lot of foam in the created paints and even after one week. The paints were slowly stirred in an attempt to remove the foam but it was not successful in all cases. The analytical test were preformed anyway. Creaming in the foam test could be seen after approximately two months.

Binder B5: *Fully reacted siloxane (55%), unknown content (45%)*

Physical data:

Table A.6: Physical data for binder B5

Active Content [%]	**Density** $[g/cm^3]$	**Appearance**	**Hazards**
55	1	white	corrosive liquid

Observations during project: Binder B5 in itself is low viscous and similar to binder B1. A characteristic property of the formulated paints with binder B5 is that they have a quite homogeneous color. Furthermore, there were not any lumps in the paint but they were foamy.

Binder B6: *Fully reacted siloxane (52%), unknown content (48%)*

Physical data:

Table A.7: Physical data for binder B6

Active Content [%]	**Density** $[g/cm^3]$	**Appearance**	**Hazards**
52	1	white	flammable, aquatic chronic, reproductive toxic, health hazard

Observations during project: Binder B6 in itself is low viscous and similar to binder B1. The formulated paints with binder B6 are foamy but without lumps.

Binder acrylate: *acrylate dispersion (44%), unknown content (56%)*

Physical Data:

Table A.8: Physical data for binder acrylate

Active Content [%]	**Density** $[g/cm^3]$	**Appearance**	**Hazards**
44	1	white	not classified as hazardous

Observations during project: Binder acrylate differs a bit from the other binders. The binder is more viscous than binder B1 and all binders similar to binder B1. The color of the binder is more of a yellow shade than the white shade of the other binders. In the formulated paints with binder acrylate, the pigments separated quite fast. Only after one day, the gray paint with PVC of 20% had separated in to three layers of pigment; gray, white and black. Furthermore, there were low amount of foam in all paints except for the yellow paint with PVC of 30% which had a lot of foam. Furthermore, there were no lumps in the paints.

B

Appendix 2

Table B.1: Viscosity measurements for Monobinder Paints with B1

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray B1 20%	1	6	1,33	180
	1	12	2,66	120
	1	30	6,65	73
	1	60	13,30	51
Gray B1 30%	2	6	1,33	1760
	2	12	2,66	1055
	2	30	6,65	543
	2	60	13,29	330,9
Black B1 20%	1	6	1,33	101
	1	12	2,66	73
	1	30	6,65	51,8
	1	60	13,30	35,9
Black B1 30%	2	6	1,33	1455
	2	12	2,66	897
	2	30	6,65	495
	2	60	13,29	315,5
Yellow B1 20%	0	6	1,39	15,6
	0	12	2,79	11,55
	0	30	6,97	8,3
	0	60	13,94	6,75
Yellow B1 30%	2	6	1,33	1289
	2	12	2,66	805
	2	30	6,65	447,9
	2	60	13,29	290

Table B.2: Viscosity measurements for Monobinder Paints with B2

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray B2 20%	3	6	1,29	7059
	3	12	2,58	4090
	3	30	6,45	2012
	3	60	12,89	1198
Gray B2 30%	3	6	1,29	5380
	3	12	2,58	3120
	3	30	6,45	1488
	3	60	12,89	858
Black B2 20%	4	6	1,26	12100
	4	12	2,52	7350
	4	30	6,29	3579
	4	60	12,59	2150
Black B2 30%	3	6	1,29	6360
	3	12	2,58	3540
	3	30	6,45	1688
	3	60	12,89	970
Yellow B2 20%	3	6	1,29	5980
	3	12	2,58	3550
	3	30	6,45	1848
	3	60	12,89	1148
Yellow B2 30%	3	6	1,29	4980
	3	12	2,58	2870
	3	30	6,45	1423
	3	60	12,89	848

Table B.3: Viscosity measurements for Monobinder Paints with B3

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray B3 20%	3	6	1,29	4460
	3	12	2,58	2500
	3	30	6,45	1180
	3	60	12,89	686
Gray B3 30%	3	6	1,29	3800
	3	12	2,58	2130
	3	30	6,45	1004
	3	60	12,89	584
Black B3 20%	4	6	1,26	4559
	4	12	2,52	2560
	4	30	6,29	1204
	4	60	12,59	696
Black B3 30%	2	6	1,33	3089
	2	12	2,66	1747
	2	30	6,65	835
	2	60	13,29	479,5
	3	6	1,29	3400
	3	12	2,58	1920
	3	30	6,45	916
	3	60	12,89	534
Yellow B3 20%	2	6	1,33	2525
	2	12	2,66	1532
	2	30	6,65	805
	2	60	13,29	495,5
	3	6	1,29	2740
	3	12	2,58	1680
	3	30	6,45	876
	3	60	12,89	550
Yellow B3 30%	2	6	1,33	2840
	2	12	2,66	1645
	2	30	6,65	826
	2	60	13,29	493
	3	6	1,29	3100
	3	12	2,58	1820
	3	30	6,45	904
	3	60	12,89	546

Table B.4: Viscosity measurements for Monobinder Paints with B4

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray B4 20%	3	6	1,29	7719
	3	12	2,58	4430
	3	30	6,45	2160
	3	60	12,89	1266
Gray B4 30%	3	6	1,29	4780
	3	12	2,58	2760
	3	30	6,45	1296
	3	60	12,89	746
Black B4 20%	3	6	1,29	4900
	3	12	2,58	2830
	3	30	6,45	1368
	3	60	12,89	798
Black B4 30%	3	6	1,29	3980
	3	12	2,58	2270
	3	30	6,45	1088
	3	60	12,89	636
Yellow B4 20%	1	6	1,33	154
	1	12	2,66	100
	1	30	6,65	62,8
	1	60	13,30	44,6
Yellow B4 30%	3	6	1,29	3440
	3	12	2,58	2000
	3	30	6,45	1004
	3	60	12,89	602

Table B.5: Viscosity measurements for Monobinder Paints with B5

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray B5 20%	3	6	1,29	4420
	3	12	2,58	2480
	3	30	6,45	1148
	3	60	12,89	660
Gray B5 30%	2	6	1,33	2785
	2	12	2,66	1580
	2	30	6,65	754
	2	60	13,29	433,5
	3	6	1,29	3080
	3	12	2,58	1750
	3	30	6,45	824
	3	60	12,89	484
Black B5 20%	3	6	1,29	4940
	3	12	2,58	2780
	3	30	6,45	1291
	3	60	12,89	748
Black B5 30%	2	6	1,33	3160
	2	12	2,66	1815
	2	30	6,65	863
	2	60	13,29	496,5
	3	6	1,29	3620
	3	12	2,58	2050
	3	30	6,45	960
	3	60	12,89	562
Yellow B5 20%	3	6	1,29	3579
	3	12	2,58	2130
	3	30	6,45	1096
	3	60	12,89	682
Yellow B5 30%	2	6	1,33	2420
	2	12	2,66	1452
	2	30	6,65	750
	2	60	13,29	455,5
	3	6	1,29	2620
	3	12	2,58	1580
	3	30	6,45	808
	3	60	12,89	505

Table B.6: Viscosity measurements for Monobinder Paints with B6

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray B6 20%	2	6	1,33	2705
	2	12	2,66	1632
	2	30	6,65	820
	2	60	13,29	482,9
	3	6	1,29	2660
	3	12	2,58	1610
	3	30	6,45	792
	3	60	12,89	485,9
Gray B6 30%	2	6	1,33	2010
	2	12	2,66	1232
	2	30	6,65	624
	2	60	13,29	371,5
Black B6 20%	3	6	1,29	3060
	3	12	2,58	1870
	3	30	6,45	948
	3	60	12,89	588
Black B6 30%	2	6	1,33	2595
	2	12	2,66	1567
	2	30	6,65	796
	2	60	13,29	471
	3	6	1,29	11900
	3	12	2,58	7250
	3	30	6,45	3680
	3	60	12,89	2320

Table B.7: Viscosity measurements for Monobinder Paints with Crilat

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Gray Acrylate 20%	1	6	1,33	389
	1	12	2,66	258
	1	30	6,65	162
Gray Acrylate 30%	2	6	1,33	1815
	2	12	2,66	1112
	2	30	6,65	592
	2	60	13,29	369
Black Acrylate 20%	1	6	1,33	379
	1	12	2,66	247
	1	30	6,65	167,6
Black Acrylate 30%	2	6	1,33	1764
	2	12	2,66	1102
	2	30	6,65	592
	2	60	13,29	371,5
Yellow Acrylate 20%	1	6	1,33	168
	1	12	2,66	124
	1	30	6,65	91
	1	60	13,30	75
Yellow Acrylate 30%	2	6	1,33	885
	2	12	2,66	572
	2	30	6,65	341
	2	60	13,29	235,5

Table B.8: Viscosity measurements for Polybinder Paints

Paint	**Spindle no**	**RPM**	**Shear rate [1/s]**	**Viscosity [mPa · s]**
Poly-B5-M	2	6	1,33	2215
	2	12	2,66	1355
	2	30	6,65	716
	2	60	13,29	443
	3	6	1,29	2320
	3	12	2,58	1430
	3	30	6,45	760
	3	60	12,89	490
Poly-B5-H	3	6	1,29	4080
	3	12	2,58	2279
	3	30	6,45	1060
	3	60	12,89	628
Poly-B2-M	3	6	1,29	3660
	3	12	2,58	2190
	3	30	6,45	1108
	3	60	12,89	682
Poly-B2-H	3	6	1,29	5820
	3	12	2,58	3300
	3	30	6,45	1580
	3	60	12,89	924
Poly-B6-M	2	6	1,33	1925
	2	12	2,66	1185
	2	30	6,65	624
	2	60	13,29	384,5
	3	6	1,29	2020
	3	12	2,58	1250
	3	30	6,45	664
	3	60	12,89	430
Poly-B6-H	2	6	1,33	2355
	2	12	2,66	1435
	2	30	6,65	723
	2	60	13,29	429
	3	6	1,29	2540
	3	12	2,58	1550
	3	30	6,45	792
	3	60	12,89	488
Poly-Acrylate-Ref	2	6	1,33	1285
	2	12	2,66	817
	2	30	6,65	474
	2	60	13,29	316,5

C

Appendix 3

Table C.1: The type of transportation for the binders and silane/siloxane content in the binders. If transportation type is not displayed in the table for the silane/siloxane, then the binders are manufactured at the same place.

Binder	Transportation Binder	Transportation Silane/Siloxane
B1	Truck	-
B2	Ship	Truck
B3	Ship	Truck
B4	Ship	Truck
B5	Truck	-
B6	Aircraft	-
Acrylate	Truck	-

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