TALLINN UNIVERSITY OF TECHNOLOGY
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Department's title

ALTERNATIVE MATERIALS TO NATURAL LEATHER AND THEIR APPLICATION IN BAG DEVELOPMENT

ALTERNATIIVSED MATERJALID LOODUSLIKULE NAHALE JA NENDE KASUTAMINE KOTTIDE VALMISTAMISEL

MASTER THESIS

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Tallinn 2020

(*On the reverse side of title page*)

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THESIS TASK

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Thesis topic:

(in English) *Alternative materials to natural leather and their application in bag development*

(in Estonian) Alternatiivsed materjalid looduslikule nahale ja nende kasutamine kottide valmistamisel

Thesis main objectives:

1. To test the materials' quality and processability of two different types of alternative leathers: Piñatex® material and cork leather-like material
2. Product development of three different envelope bags made from Piñatex® material and cork leather-like material
3. Explore different leather alternatives, their properties and areas of applications
4. Test genuine leather, Piñatex® material, cork leather-like material, and PU covered fabric according to different standards, compare and analyse the results

Thesis tasks and time schedule:

No	Task description	Deadline
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2.	Processing technology for bags decided	17.02.20
3.	Sample products pattern making and customizing completed	21.02.20
4.	Main theory part completed	15.03.20
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6.	Embroidery and laser cutter files finished	30.04.20
7.	Sample products finished	14.05.20
8.	Master thesis completed	26.05.20

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PREFACE

This master thesis aims to explore plant-, fungi- and bacterial-based leather alternatives and test two commercially available options parallel to the real leather to analyse their suitability as alternatives. In this master thesis Piñatex® material and cork-covered fabric were chosen to be the tested alternative materials and also a small three-piece bag collection was created to evaluate the production properties of these materials.

I would like to thank my supervisor Tiia Plamus, a senior lecturer at Tallinn University of Technology, and co-supervisor Kersti Merimaa, a lecturer for their advice and support along the way.

Keywords: leather alternatives, leather, bag collection, master thesis

INTRODUCTION

Leather is a natural material that has been used since the very beginning of human history. Natural leather varies in thickness and properties due to originating from different animals and also different areas of the skin. There is a great variety of leather materials created to suit different needs such as stiff and strong sole leather of a heavy boot, the soft and stretchable leather of women's gloves. Nowadays it has been more topical and visible in media that current leather manufacturing technologies are often very harmful to the environment, furthermore animal activism and the increasing popularity of the vegan lifestyle are encouraging textile developers to find more sustainable alternatives.

The aim of this thesis is to research different leather alternatives that are advertised to be completely cruelty-free (no animals harmed) and more sustainable than petroleum-based PU (polyurethane) and PVC (polyvinyl chloride) covered counterparts. For this goal two commercially available leather alternatives- Piñatex® and cork leather-like material were tested parallel to sample of vegetable-tanned leather and PU-covered fabric to see if the new alternative materials are capable to compete with natural material. Three sample envelope bags were also designed and produced to analyse the processability and handling of Piñatex® material and cork leather-like material.

This thesis consists of ten chapters. The theoretical part gives an overview of natural leather and its different alternatives, leather products, and production methods. The practical part has two main parts. First part is about testing Piñatex®, cork-covered fabric, PU covered fabric, and vegetable-tanned leather and the second part is about the development and production of the sample bags.

The first chapter is about material development and the need behind that. Explaining why there is such an increase in leather alternatives development.

The second chapter is about natural leather and its properties and environmental impact.

The third chapter is about genuine leather alternatives and a short overview of synthetic alternative materials and their properties given as well as an overview of more sustainable leather alternatives that are based on renewable resources and are mainly plant-, fungi-, or bacterial-based.

The fourth chapter is about the production of three different types of leather alternatives- Piñatex®, cork-covered fabric, and fungi leather-like material.

The fifth chapter is about traditional leather goods giving a short overview of some of the main product categories that are often made of leather and need suitable leather alternatives that could withstand the use.

The sixth chapter is about processing technologies and equipment that could be used for leather or leather alternatives. Traditional cutting technologies include cutting with knives and scissors, laser cutting, and die-press. Possible material joining techniques include sewing, welding, and adhesive bonding. Some material customizing methods- engraving, embroidery, and textile printing, were also researched.

The seventh chapter describes different test methods and standards that were used when testing Piñatex® material, cork-covered fabric, PU covered fabric, and vegetable-tanned leather.

The eighth chapter is about the obtained test results of different material testing methods described in chapter seven.

The ninth chapter is about the product development and producing process of the three sample envelope bags and bag straps. This chapter includes designing phase, pattern making, creating the laser cutter files, embroidery files, and printing designs as well the final production technology and product maintenance.

The tenth chapter is a concise discussion about the results of the practical part of the thesis.

1 IMPORTANCE OF MATERIAL DEVELOPMENT

The global textile industry is in constant change and development due to the changes in consumers' behaviour and preferences, and manufacturers' technological capabilities. Alongside with growth of smart, interactive, and electronic products, one of the biggest trends is a movement towards more sustainable products and development processes, slow fashion, also waste reduction and more effective recycling methods. The textile industry is responsible for a huge amount of overall environmental damage globally, as our planet is suffering from rising temperatures and resulting natural disasters, and increasing the human population is putting pressure on shrinking amounts of agricultural land, oil and mineral reserves, and clean water supplies [1]. The material development part of the textile industry is concerned with making products more environmentally-friendly, but one side of that direction is also the increasing interest in cruelty-free vegan materials, mainly leather alternatives.

Leather as a material for clothing and accessories has a long history but is nowadays recognized as an environmentally harmful material due to chemicals involved in leather processing and increasing the audience of animal activism. There is an increasing demand for cleaner and fairer fashion supply as due to media and internet society there is a lot more transparency on the manufacturing side of the fashion industry [2]. Due to social media campaigns and celebrity representers, the industry is getting pushed to be more sustainable, and where there is a consumer market, the product line will follow [2]. The clients are interested in leather alternatives with the look, feel, and performance similar to animal originating material. Veganism is more than just a plant-based diet. It is a way of living with a goal to exclude, as much as possible and practicable, all forms of exploitation of, and cruelty to, animals for food, clothing or any other purpose including animal-derived materials, products tested on animals and places that use animals for entertainment [3]. The petroleum-based faux leather materials have been on a market for a long time as cheap alternatives to leather but these materials also cannot be named environmentally friendly choices as they rely on non-sustainable raw material, their manufacturing process includes high amounts of various chemicals and materials that are not biodegradable.

There is already a great variety of different sustainable mostly plant-based leather alternatives developed and some of them can be seen on a graphic in Figure 1.1 below, showing how far along is currently the material production process. Those materials have different approaches to sustainability and advantages/disadvantages due to the originating raw materials used in the process. Fruitleather is a project that is in the earliest stages when compared to other materials on the graphic and the prototype material is not yet suitable for commercial production and use. Most of the materials are already operational and are produced to some extent having sample products or collections made of them. Piñatex® material, BARKTEX® material, Malai, and different cork leather-like materials are already in commercial production and can be openly purchased, although materials are still in improvement and prices rather high. All these materials in Figure 1.1 are discussed more thoroughly in chapter 3.2.

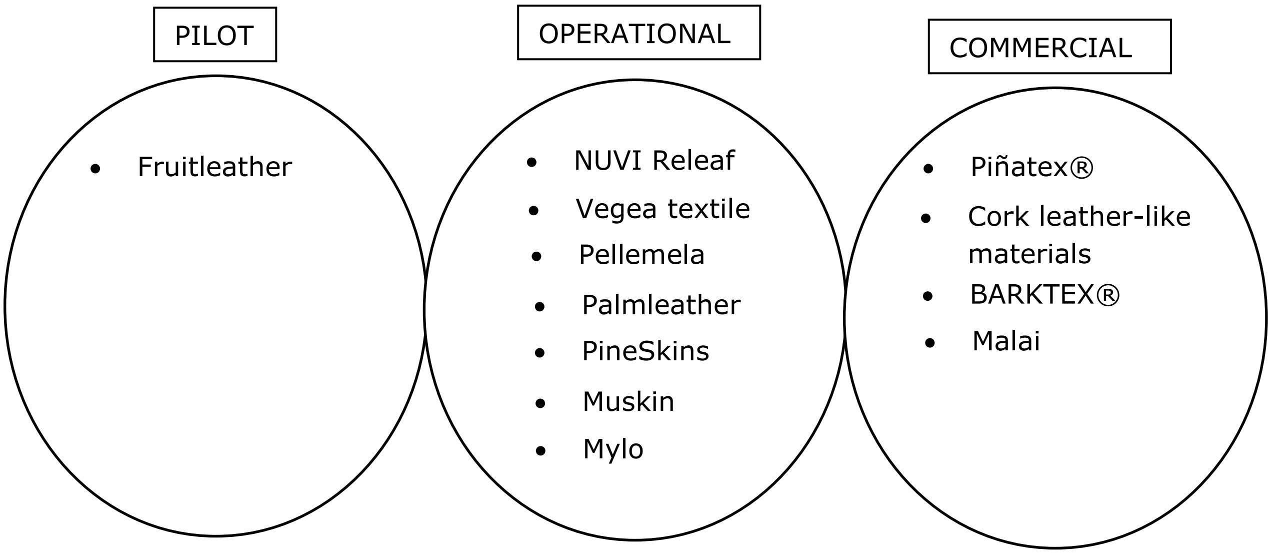


Figure 1.1 The current development situation of different sustainable leather alternatives

2 NATURAL LEATHER

2.1 Natural leather properties

Term "leather" is used when the outer part of the animal or reptile skin has its hair removed and the surface is finished for production. Term "suede" is used when the inside surface of the skin is finished for the production. Sheepskin and lambskin are the skins with fleeces unshorn. [4]

Leather varies in thickness due to originating from different animals and also different areas of the skin. Therefore cutting leather garments needs experience and knowledge of a specialist. The structure, handle and drape of leather used in fashion varies a lot. [4] The different varieties are the stiff and strong sole leather of a heavy boot, the soft and stretchable leather of women's gloves, the flexible membrane which has to withstand repeated distortion for about forty years in a gas meter, mouldable leathers used as oil seals and pump washers, wash (chamois) leather and many others. [5] Different types of leathers include: antelope, buckskin, cabretta, calfskin, chamois, cowhide, crocodile, deerskin, doeskin, goatskin, horse, kid, lambskin, nappa (lamb), patent, pigskin, fishskin, sheepskin, sheerling, snakeskin, split skin, and others. [4]

Figure 2.1.1 Examples of fish leather [6]

Examples of different common types of leather:

- Suede (pig) is a leather that has medium weight and thickness with low drape, shear, or stretch. The main uses include skirts, trousers, jackets, coats. [4]
- Chamois (calf) is a leather that has medium weight, thickness, drape, shear, and stretch. The main uses include jackets, skirts, and accessories. [4]
- Foil transfer or embossed (calf) is a decorative leather that has medium weight and thickness, but low drape, shear and stretch. The main uses include novelty clothing and accessories. [4]

Figure 2.1.2 Metallic foil transferred patent leathers [7]

All those materials have very different mechanical behaviour characteristics partly because these leathers originate from the natural structure of the skin and have therefore natural uniqueness and defects, and partly because of the choice of the manufacturing process. Due to such a wide range of variability, it is not possible to clearly define and measure the properties of "leather", only properties of particular types of leather. Even when only one category of leather is considered, the very substantial differences in properties between samples are observed in practice, so that inter-laboratory comparisons are not readily made. One of the most striking common features of many types of leather materials is their ability to withstand repeated flexing without failure. [5]

The chemical and physical properties of leather vary depending on the location from which the test sample is taken. According to the Standard Practice for Sampling Leather for Physical and Chemical Tests (ASTM D2813), the sampling should be random for finished leather material and fully fabricated leather products for physical and chemical testing, and the sample should be cut from only one side of the backbone with their long dimension perpendicular to the backbone line. Specimens need to be taken from different parts of the shoulder, belly tail and the number of specimens depends on the reliability of the test results. [8]

Leather is considered to be one of the strongest flexible sheet materials, as it has high tensile strength and very high tear strength, which is caused by the structure where the fibres have random orientation and do not have a fixed tear path. [8] Differences in fibre structure and orientation can be observed as one proceeds from the outer, epidermal surface, through the grain layer to the main fibrous structure of the remainder of the skin. Therefore, the theoretical studies about the properties relating to the structure are very complicated and require extensive work. [5] Generally, pigskins have much weaker tear resistance and therefore cannot be used in some types of products. The elongation of leather can be controlled about 15-73% by selecting suitable tanning and fat liquoring processes. Leather is suitable for usage in harsh and difficult environmental conditions, as it has excellent flexibility over a wide temperature and moisture range. Leather as a material is also good for products that have to provide an additional safety feature due to its puncture resistance, which also contributes to its long-wearing. Furthermore, leather is capable of absorbing and transmitting moisture and has the ability to cool in hot weather and insulate in cold weather, and is windproof. Leather is suitable for moulding and its properties stay the same after being permanently deformed into new shapes. [9]

Table 2.1.1 Physical properties for leather used as shoe-upper [9]

Property	**Value**
Tensile strength	15.3 - 37.5 MPa
Elongation at break	29.5 - 73.0 %
Stitch tear strength	1280 - 2275 N/cm
Thickness	1.5 - 2.4 mm
Bursting strength	1.1 - 24.5 kN/cm
Apparent density	0.6 - 0.9 g/ cm^3
Real density	1.4 - 1.6 g/cm
Heat resistance	Shrinks depending on moisture; anhydrous decomposition at 160-165 ºC

2.2 Natural leather environmental impact

The main advantage of leather is that most hides are biodegradable by-products of the meat and dairy industry, but this is not a strong advantage as the meat and dairy industries also have a really high environmental footprint compared to other food sources. [10] The leather industry has a significant negative environmental impact due to the pollution, which is mostly caused by tannery wastes created during leather processing. The skin is treated with over 75 chemical and mechanical operations throughout its processing. [11] Tanning is a complicated process and is usually the most harmful part of skin processing for the environment, involving approximately 20 stages and up to 250 chemicals, including harmful chemicals like aldehyde and cyanide, and heavy metals such as hexavalent chromium, zinc, and lead to halt decomposition [12].

While vegetable tanning alternatives are far gentler to the environment, they are much more expensive, therefore the majority of traditional leather in the world is still tanned using chromium. And because leather is often imported from low-resource countries with unsafe working conditions, many leather workers are constantly exposed to toxic chemicals, and seriously damaging their health. [13] The tanning processes contribute to chemical oxygen demand (COD), total dissolved solids (TDS), chlorides, sulphates, and heavy metal pollution and the chemicals discharged into aquatic systems end up in highly polluted sediments and salinization of rivers. European Chemical Agency (ECHA) has prioritized some of the hazardous chemicals used in leather under Substances of Very High Concern (SVHC) and substances for Authorization. This has resulted in the rise of greener technologies and alternatives for the classical leather industry. [14]

There are two main categories of technical methods for making leather industry greener, of which the first group involves the introduction of processing technologies by decreasing the effluent pollution load, avoiding the use of harmful chemicals and producing solid wastes that can be used as by-products. The second category focuses on the treatment of wastewater, handling, and processing of solid waste in an environment-friendly manner. Both methods have been applied to prevent a negative impact on the environment during leather production. For the best result, it would be preferable to have a combination of both methods. Using the best available technologies and optimized systems could help the classical leather industry to be more environmentally friendly. [14]

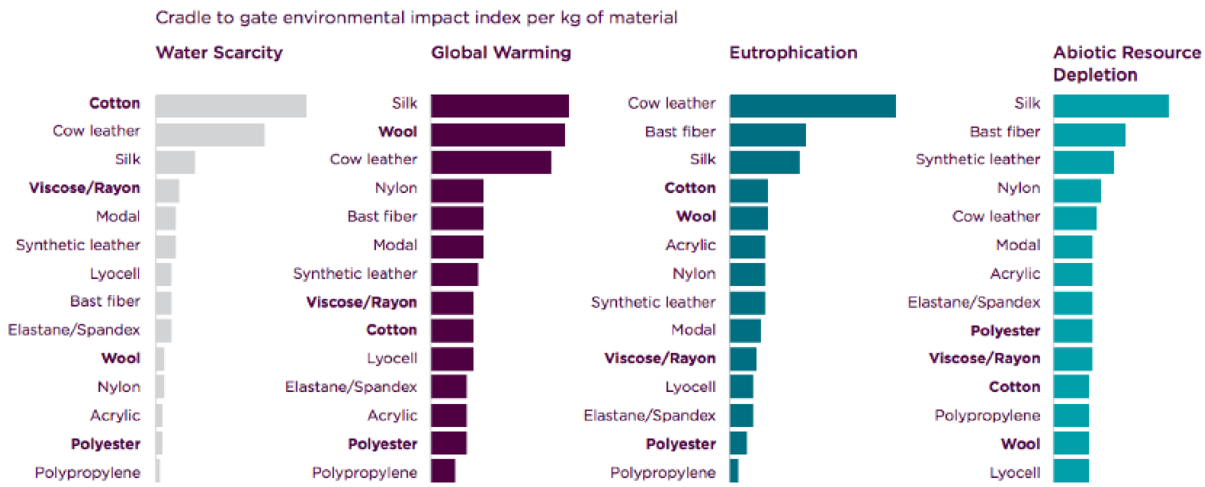


Figure 2.2.1 Environmental impact of different materials [15]

It has been claimed that when comparing natural cow leather and synthetic leather, the synthetic alternative has approximately a third of the environmental impact of a natural material. (See Figure 2.2.1) According to Kerings' 2015 EP&L statement, there can be over tenfold differences in the environmental impact of different leathers, based on their type and origin, and also how the animal was raised, and how the tanning process took place. That means, that a choice towards alternative materials could directly improve a product's footprint. [15]

3 ALTERNATIVE MATERIALS FOR NATURAL LEATHER

3.1 Different synthetic materials and their properties

Artificial leather is a leather substitute that combines natural or synthetic fibre fabric with plasticized polyvinyl chloride (PVC) or polyurethane (PU) coating. Coatings can be dense or foamed depending on the application, but the main goal is to give the appearance of natural leather. [16] Another common term used for these materials is “pleather” (plastic leather) which is more of a slang term. [17]

Some of the advantages of artificial leather compared to genuine leather are the following: it has uniform properties in all directions, it is crease-free, washable, easy to care, it has a uniform surface and low price. [16]

Polymer coating on textile backing not only provides the possibility to produce leather-like appearance but also improves properties of the fabric. Polymer-coated textile materials have a wide range of applications, from the textile industry to technical textiles. One of the main advantages of polymer-coated textiles is their water impermeability, but on the other hand those materials also have air and water vapour permeability. The coating substrate can be non-woven, woven, or knitted fabric depending on the final use and desired properties. Coated leather-like materials can be similar to natural or even they can surpass the properties of natural fibres, resulting in an increasing application for coated materials, but the quality-level of different polymer coated materials can differ a lot. [16]

Polyurethane is washable and can also be dry-cleaned, furthermore, PU coating allows some airflow through the material. Polyvinyl chloride coating on the other hand does not allow airflow through the material and is more difficult to clean, as it cannot be dry-cleaned because the cleaning solvents can make this material uncomfortably stiff. [17]

There are many different types of artificial leathers:

- Poromeric Imitation Leathers (also known as poromerics) are made from a plastic coating which is commonly a polyurethane, on a fibrous base layer which is typically a polyester. The term poromeric comes from terms of micro-porous and polymeric. The main advantages over natural leather are its durability and high gloss finish which is easy to maintain as it can be cleaned with a damp cloth. Poromerics’ main disadvantages are stiffness and relative lack of breathability. [16]

- Koskin is an artificial leather material commonly used for laptop cases. This material is made to look and feel like authentic leather. In Swedish, Koskin means cow's skin, which can confuse costumers. [16]
- Leatherette is a type of artificial leather, made by covering a fabric base with a plastic layer, commonly PVC. The main disadvantage of leatherette is the non-porous structure that does not allow air to pass through, therefore also sweat can accumulate causing discomfort. One of the primary advantages is that this material requires only little maintenance in comparison to leather and does not crack or fade as easily. [16]
- Vegan Leather is a generic name for an alternative to traditional leather. As the term suggests, this material may be chosen for ethical reasons but also as a designed material that may have different properties but a similar look to the genuine leather. [16]

There are different manufacturing processes that can be used for artificial leather, such as direct coating process, transfer coating process, and wet process. [16]

- The direct coating process is the oldest technology used to manufacture artificial cloth. In this process the plastisol coating is directly added to a woven fabric before passing through the oven and then being embossed. This technology had limited use in industries due to the final properties and was mostly used in the bag and luggage industry. [16]
- The transfer coating process is a technology where the coating is done on a release paper and then the film is released and laminated onto the base fabric, which is commonly a knitted fabric. The end product from this process has more variety and can be used in several industries such as upholstery, shoes, bags, etc. [16]
- Wet process or coagulation is a process which is used for producing PU cloth. First, the base fabric is dipped into a bath of PU and then the PU is impregnated into the base fabric. Compared to PVC, PU covered cloth is more flexible and has a higher tensile, tearing, and bursting strength and therefore PU cloth has an advantage when used in making products with high-stress tolerance like shoes and luggage bags. PU cloth is washable, can be dry-cleaned, and allows some air to flow through, but PVC coated cloth has very low air permeability and cannot be dry-cleaned, because that would cause the coated textile to stiffen. PU leather material can also be made using split leather in this process. There are different coating processes used for coating the fabric, such as calendar coating, solution coating dispersion coating. Dispersion coating is believed to be the best technology. [16]

3.2 Different plant-, fungi- and bacterial-based leather materials and their properties

Compared to poromeric imitation leather, which uses polyester as a base layer with PU plastic coating, and leatherette, that uses PVC, alternatives that are plant-, fungi- or bacterial-based, are considered to be the most environmentally friendly substitutes for real leather. There are different types of these natural raw material-based leather alternatives, that are made from natural raw materials such as leaf fibres, fruit waste, fungi, tree bark, and they all have rather distinct production methods and material properties.

3.2.1 Leather alternatives from leaf fibres

Piñatex®

Piñatex® is an alternative cruelty-free leather-like textile material that is made of pineapple leaves. The used raw material is a by-product of the fruit industry, and using them creates an additional income stream for farming communities. Pineapple leaves are usually discarded or burned. [18] Globally approximately 25 million tonnes of this pineapple waste are generated each year [19] Piñatex® is claimed to be a natural, sustainably produced textile material, developed for use as a sustainable alternative to mass-produced leather and polluting synthetic materials. [12]

One of Piñatex®'s biggest advantages is that it doesn't need any additional environmental resources like land, water, food, and fuel. Piñatex® doesn't use any chemicals on the Cradle2cradle list of banned substances used in production. [10] The final leather-like fabric is breathable, flexible, and has good production qualities. One of its advantages when comparing with real leather is, that it is also available to purchase on a roll, avoiding the material wastage caused by irregularly shaped hides of natural leather. Other great advantages of Piñatex® material is that it weighs and costs less than an equivalent amount of leather. [18]

Piñatex® has a closed-loop, cradle to cradle, production – residual leaf biomass is used as natural fertilizer or biofuel. Once the fibre has been stripped from the leaf the leftover biomass is retained to use as a natural fertiliser or biofuel, offering a further economic prospect. [12]

Piñatex® upcycles waste taken from local pineapple plantations in the Philippines. Different local factories separate the strands of leaves and felt them together into a non-woven fabric. Approximately 16 pineapples or 480 leaves are used to create a single square metre of Piñatex® [18]

In the production process the leaves are fed through a decorticating machine where they are separated into fibres and biomass. As a next step, chlorophyll and plant gum are removed, leaving behind a fibre mass that is felted together into a non-woven mesh and given a protective coating. [19]

There are four different lines of Piñatex® material, Original, Pluma, Mineral, and Performance, but all of them have the same base material, Piñafelt. The coating of Piñatex® Original, Pluma, Mineral lines is a water-based PU resin which makes 10% of the total material composition, but the coating of Piñatex® Performance is a high solid PU and bio-based PU that makes up to 42% of the final material composition. [20]

Currently, Piñatex® uses a non-biodegradable protective coating that increases durability, although the company is trying to find a natural alternative that would make the fabric fully biodegradable. [18] The PU coating currently used in Piñatex® material production is REACH compliant and has no detectable volatile compounds within the collection. The base material of Piñatex®, that is made of 80% of pineapple leaf fibre (PALF) and 20% of polylactic acid (PLA) fibres, is claimed to be biodegradable under controlled industry conditions. [20]

NUVI RELEAF teak leather

Teak leaf leather-like textile material is used by brand NUVI NOMAD, which is inspired by the ancient Thai tradition of Saa papermaking. NUVI NOMAD collaborates craftsmanship and natural materials with a modern design. NUVI NOMAD uses a slow fashion approach and all the products are handcrafted. Teak leather is light-weight, durable, water- and dirt-resistant, anti-bacterial, anti-fungal, and non-toxic alternative to leather. [21]

NUVI NOMAD is a PETA-approved vegan brand and NUVI RELEAF leather is 98% natural and free of synthetic polymers and animal products. [22]

The production process of the material starts with fallen leaves that are handpicked and selected from the forest in Chiang Mai, with the great help of Pi Por's local team, the surface of the material is then sealed with wax and refined by NUVI NOMAD's special technique. [23]

Figure 3.2.1.1 Bag made with NUVI RELEAF leather [21]

Currently, this material has been used for making handbags and small accessories. Example of a NUVI RELEAF material can be seen in Figure 3.2.1.1.

3.2.2 Leather alternatives from fruit waste

Vegea textile

Vegea textile project started in 2016 for the production of bio-based technical textiles from vegetal raw materials and winemaking by-products that remain after the crushing of the grapes during wine production. Grape marc is a fully vegetal raw material that consists of grape skins, seeds, and stalks. The project aims to produce bio-based materials that can be used in fashion design, transportation, and packaging. [24]

Approximately 27 billion litres of wine is produced in the world each year, and with it also a huge amount of waste- around seven billion tons of stalks, skins, and seeds. These by-products collectively referred to as "pomace", are a nutrient-rich organic mix which is often used as organic fertiliser or animal feed. [13]

Vegea's wine leather looks and feels like natural leather and has similar properties. One of its biggest advantages is that it doesn’t need additional land and water to produce the raw material. And it doesn't require a complex and toxic tanning process. [24]

Pellemela

Pellemela is created through the polyurethane coagulation process, that differs from the classical process of the normal coagulated fabrics or nonwovens, by adding polyurethane blend to ecological products coming from the waste of vegetal production. [25] Pellemela apple-based material includes 76% of apple flour, obtained from dehydrated and powdered apple peel and cores, water, and natural glue. The ingredients are compacted together by using a pasta roller. The pasta roller is used to stretch and cut the material. [26]

Apple is an ecological and natural product, that gives also unique technical and organoleptic features. The high percentage of organic and natural materials in this textile material increases its' breathability without modifying thermo-sensitiveness and also makes the product eco-friendly, non-toxic, and bio-compatible and helps to reduce CO2 emissions. Pellemela material production is aimed towards environmental preservation by using resources that otherwise would be disposed of as waste or burned. [25]

The price of Pellemela is now equivalent to that of animal leather, but the minimum order is 300 meters. [27]

Fruitleather

Fruitleather is a leather alternative that is made from fruit waste. Every year there is globally thrown away approximately 1.3 billion tons of food, and from all the fruit that is produced for consumption, about 45% gets thrown away. Furthermore, farmers tend to leave up to 40% of their harvest in the fields, because it does not meet the cosmetic standards for the supermarkets. [28]

Fruitleather Rotterdam is developing a new, eco-friendly process that converts leftover fruits into a durable leather-like material. The material is being further developed so that it will be strong enough to be used for shoes, handbags, and other products in the future. By collecting waste that is already present, there won't be a need for new virgin resources to make the material. [28]

Fruitleather uses an eco-friendly process where the discarded fruit is transformed into sheets of leather-like material. The process involves mashing, cooking, and drying of the fruit waste. In order to get a satisfactory leather-look, final finishing is applied. The Fruitleather can be coated or embedded with a print before being made into final products. [28]

3.2.3 Leather alternatives from tree bark

Cork leather

Cork leather is a natural and environmentally friendly leather-like material, that is made from the bark of the cork oak tree. Cork tree develops naturally thick, an extra layer of bark on its outside, that functions as its structural axes of protection. Bark gets thicker over the years and therefore removing bark from the tree is good for the tree as it helps the tree to breathe and grow better. Cork leather is waterproof, stain-resistant, and has high durability. [29]

The cork tree needs to be 25 years old before it can be harvested for the first time, but the first harvest is not usable. The second harvest can be done after 9 more years, and then the material can be used for textile purposes. [29] The texture of the cork gets smoother with years and after several harvests. [30]

When the bark is removed from the tree, cork is left to dry for 6 months and after that it is being steamed and boiled so that the cork cells expand and material gets its needed elasticity. Finally, the blocks of cork are cut into thin sheets and supportive fabric backing is attached. [29] Usually, those thin cork sheets are glued to a fabric of cotton and polyester blend or polyurethane backing and afterwards treated with a nontoxic sealing coating that is not environmentally harmful. This last step is needed to protect the final material from dirt. [30]

Palm leather

"Palmleather" project was started with the intention to find a cheap plant-based alternative for animal leather, synthetic polymers, and rubber and it is created by dipping the dry and brittle leave from the Areca Betel Nut into a biological softening solution that the company designed in 2011. A few days after dipping the material turns permanently soft, flexible and shows great aesthetic quality. Another good aspect is that this palm material can be processed on conventional machines. [31]

Areca Betel Nut leaves used for the production are waste from general food-production and are being upcycled during the production giving them new value. The production process is designed to minimise the waste and the waste leaves can be returned to the natural compost cycle. The biological softening solution used during processing is claimed to have no harmful effect on people, animals, or nature, on a small or large scale. On the contrary, all ingredients are graded for human consumption and the compounds are easily absorbed in the local biotope. Palm leather also strives to minimise water consumption during the process. The goal is to use a maximum of 20 litres per m2. [31]

The raw material is sustainable and if looking at the wider picture of used raw material, then in the Southern part of India 80 million Areca Betel Nut trees grow in plantations, parks, reserves, and in their natural habitat. By the estimation, 1 m2 leave material from 1 tree is utilized with the production of Areca Leave Plates, which is about 5%, so there is enough left-over material that could be used. [31]

Figure 3.2.3.1 Handbags made with Palmleather material [31]

Products developed from Palmleather material include bags (Figure 3.2.3.1), shoes, book covers, and Palmetti, a fully biodegradable slipper for the hospitality industry. The newer product is the Palmleather Filigree Rug, a niche, novel way of using these leaves in carpets and rugs for different occasions. [32]

BARKTEX®

BARKTEX® No-Buffalo is a leather alternative that is based on traditionally manufactured bark cloth. The material is claimed to be not only vegan but also more than 99% biobased, and the surface material grows naturally and permanently. [33]

The material is basically a bark cloth that is combined with the water-based acrylate resin. The material is sustainable as the raw material for Bark cloth is harvested from the renewable bark of the East African "Mutuba" fig tree and then produced in cooperation with small-scale organic Ugandan farmers. The bark cloth history started centuries ago and it is created through the process of stripping an inner layer of bark from the tree and pounding it by hand into flexible cloth, while also tripling its size and developing a characteristic rust colour. [34] This bark is harvested once a year without harming or killing those trees and each strip of bark produces just one cloth. [35] One tree is capable of yielding 30-40 cloths during its lifespan. The process of bark cloth creation has not evolved much since its inception, and still every single piece of cloth is made by hand by skilled workers continuing the tradition. [34] The suitable applications for finished BARKTEX® leather alternative material includes fashion accessories, wall coverings, furniture surfaces, and also shoes. [33]

The development of the material started at the beginning of the millennium when vegan materials were not as common and heard of. The additives used to make the material are self-made by the company in Germany but many of the processing activities take place in the factory in Uganda. Although, some of the products are also finished in Germany by commission processing or in their studio. Most of the BARKTEX® products are permanently available from the company's warehouse in Germany, while others are made according to customers' requirements. Although, in the German stockrooms are always available light brown, dark brown, black, and ivory/ créme tones, others need a few weeks to notice in advance. [33]

Currently, the production is still being carried out in small batches, consequently, unit costs and prices are rather high. [33]

PineSkins

PineSkins is a project that uses the bark of a pine tree for creating new material. Pines are considered a cheap timber in the wood industry and the bark is usually a waste. Pine bark cannot be harvested from a living tree, as a tree would die without it. The pine bark for this project is harvested in collaboration with a tree cutter business. [36]

The final PineSkins material is leather-like and surprises with its softness in contrast to the thick and harsh bark naturally on pine trees. Every piece of PineSkin material has its unique look as every piece of bark has naturally slightly different patterns, the number of holes derived from the branches, and also the width that depends on the size and age of the tree. [37] The freshly harvested bark is treated with natural ingredients that preserve its softness and later it can be coated with an enriching layer of finishing and colour pigments. [36] The final material can be seen in Figure 3.2.3.2.

Figure 3.2.3.2 PineSkins material [36]

3.2.4 Leather alternatives from fungi

Mylo

Mylo is a sustainable leather alternative made from mycelium, the underground root structure of mushrooms. Bolt Threads is still in the beginning phase in the development of this material. Mylo leather-like material is created using corn stalks and supplemental nutrients to feed and grow the mycelium. Such growth conditions like temperature and humidity are used to encourage the mycelium to grow upward and self-assemble into an organized mat of interconnected cells that are controlled precisely. The strength of the material is caused by connections. When the desired amount of the material is gained they use a natural tanning process and compress the mat to be as thin or thick as they like the final material to be. At this point, the mycelium is no longer growing. The final step is to imprint any desired pattern, which gives the final material. [38]

One of the advantages of Mylo is that it can be produced in days while it takes years for rearing animals for real leather and also there is no waste of material. Also, the land, that is used, isn’t harmed by fertilizer and upkeep. [39]

Muskin

Muskin is a 100% vegetable substance leather alternative invented by the company Zero Grado Espace, based in Montelupo Fiorentino. Muskin can be used for shoes, bags, and accessories. [40]

Muskin is completely made from the cap of Phellinus ellipsoideus, a gigantic, inedible parasitic mushroom species native to subtropical forests that feed on tree trunks, making them putrefy. [41] MuSkin is made of the external peel of this mushroom. [42]

This leather alternative acts as a thermal insulator that absorbs damp and releases it immediately, therefore limiting bacterial proliferation. This material is transpiring, water-repellent, and non-toxic which makes it a suitable choice for all the products that come into contact with the skin, due to the lack of allergic reactions. [41]

After the raw material is extracted, the material is treated in a similar way to animal leather but using only natural and environmentally friendly techniques, including the use of eco-friendly products such as eco-wax, to add special characteristics to the material. [41]

At the moment, it is possible to produce only 40-50 square metres of Muskin in a month, therefore this leather is suitable to create limited edition collections. [41] Examples of handbags made with Muskin material can be seen in Figure 3.2.4.1.

Figure 3.2.4.1 Handbags made with Muskin material [41]

3.2.5 Leather alternatives from bacterial cellulose

Malai

Malai is a bio-composite material made from entirely organic and sustainable bacterial cellulose, which has been grown on agricultural waste sourced from the coconut industry in Southern India. The coconut water that is used in the process is a waste that would otherwise be dumped but is collected from the local farmers to feed it to bacteria's cellulose production. The processing units used are also local and one small coconut-processing unit can collect 4000 l of water every day, which can be used to make 320 m^2 of Malai. [43]

Malai material feel can be compared to leather or paper and it is flexible, durable, and water-resistant. It is claimed that the material does not contain any artificial compounds that could cause allergies, intolerances, or illness. [43] Malai material can be processed into products by cutting, gluing, embossing, and has been used to make shoes, accessories, and even upholstery. [44]

The name "Malai" is inspired by the creamy flesh of the coconut which is suitable as the coconut water, which is the by-product of harvesting the coconut flesh is what sustains the bacteria while producing cellulose that is later collected and refined to get the finished Malai material. [43]

Malai material is produced in sheets of different thicknesses suitable for different needs as bacterial cellulose which is a nano-material of a three-dimensional fibrous network and glues together natural fibres via hydrogen bonding and physical entanglements forming the final bio-composite. [44] They have additionally developed a process where it is possible to create seamless three-dimensional objects using a moulding technique. The finished material is available in a range of colours that are created with mordant-free natural dyes, and it can develop a soft sheen or patina over time. [43]

It is claimed that product that is made from Malai material will last for many years if cared of properly, but if the product is not wanted anymore it could be simply put in compostable rubbish and it will naturally break down. [43] Example product, sandals made with Malai, can be seen in Figure 3.2.5.1 below.

Figure 3.2.5.1 Sandals made with Malai material [43]

3.3 Environmental impact of leather alternatives

Leather alternatives also called vegan leather or plant-based leather alternatives, don't involve any animal products. Currently there are different leather substitutes available named synthetic "leathers", "vegan" or "faux" leathers that have a variety of different base materials and range from biodegradable to fossil fuel-based [10]. The common leather alternatives are usually synthetic fabrics that are structured and printed to perform like real leather as during production, textured coating of PU, or less commonly PVC to a base fabric. PVC is potentially a respiratory irritant and a known carcinogen, furthermore, when PVC is exposed to high heat or landfilled, it starts to release dioxins linked to developmental, reproductive, and other health problems. [45]

The main issues with those materials are they are usually not effectively recyclable composites and/or made from virgin non-renewable materials. Also, leather alternatives are commonly not as durable as real leather. [10]

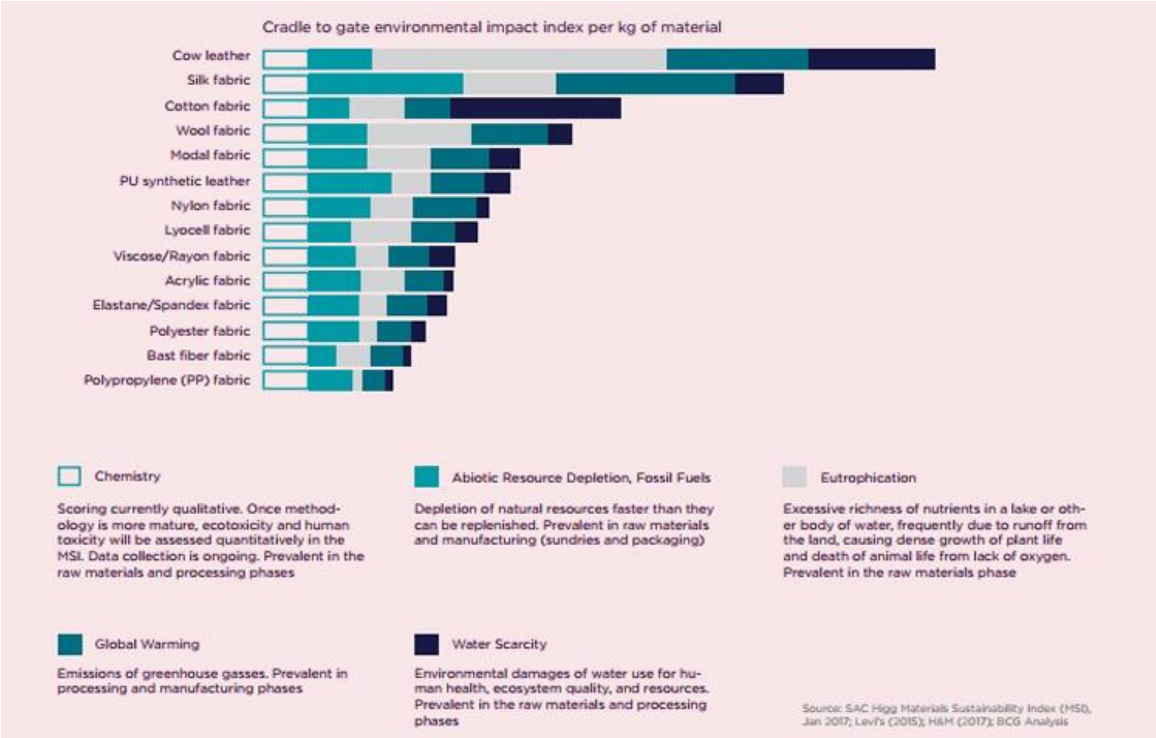


Figure 3.3.1 Cradle to gate environmental impact by material [15]

According to the Pulse of the Fashion Industry report 2017 PU covered synthetic leather has much lover cradle to gate environmental impact when compared to cow leather. As seen in Figure 3.3.1 the overall cradle to gate environmental impact of PU covered fabric is mainly lower due to lower impact on eutrophication, global warming, and water scarcity. Although, PU covered fabric has higher abiotic resource depletion and similar chemical impact. [15]

4 MATERIAL PRODUCTION PROCESS

In this chapter are more detailed descriptions of the production processes of three types of leather alternatives: Piñatex® material, cork leather-like material, and fungi leather. Those materials were chosen as an example of three more known experimental leather alternatives that also have distinctive manufacturing methods that differ from each other greatly.

4.1 Piñatex® leather

Piñatex® is made from the leaves of pineapple, which are the by-product of the fruit industry. Pineapple leaves are traditionally discarded or burned. After the fibre has been stripped from the leaf, the leftover biomass is retained to use as a natural fertilizer or biofuel, prolonging the material's life cycle and offering an extra economic income. [12] Ananas Anam works with farmers in the Philippines. The first step of production after harvesting is decortication, where fibres are extracted from the leaves. The decortication process is the extraction of green fibre without retting (Figure 4.1.1). [46] This process is done at the plantation by the farming community. Ananas Anam has developed the first automated decorticating machine to assist farmers with this process, allowing them to utilize greater quantities of the waste leaves. Usually, the quality of the fibre that is obtained by this process is lower than that of the quality obtained after retting. Decorticated fibres are thick, strong, non-divisible, and contaminated by remnants of other plant tissues, but the quality is still suitable for making the nonwoven mesh [46]. After decortication, when the fibres are separated from the remaining biomass fibres are washed (Figure 4.1.2) and left to dry (Figure 4.1.3). Leftover by-product which is bio-mass, can be further converted into organic fertilizer or biogas. [12]

Figure 4.1.1 Decortication [47]

Figure 4.1.2 Washing of the fibres [12]

Figure 4.1.3 The fibres are then hung to dry before they are turned into a non-woven textile. [48]

The fibres gained from the decortication process are degummed (Figure 4.1.4), and then made into a nonwoven textile, which is the base of the material. Ananas Anam hasn’t published its degumming method. [12] There are several possible degumming methods that they might use. Usually chemical degumming is the most common.

Figure 4.1.4 Degumming process [12]

Figure 4.1.5 Non-woven mesh [12]

The last step of the production process is finishing the fabric which is done by a company in Spain before being shipped all over the world. [48] The rolls of the non-woven mesh (Figure 4.1.5) are then transported to Spain for special finishing, which gives Piñatex® its leather-like appearance, creating a textile that is soft and flexible, yet very durable. [10] Ananas Anam uses in their production only GOTS certified pigments. [20]

Piñatex® substrate is made of natural fibres and polylactic acid fibres (PLA) which is 100% biodegradable. The resins we currently use for the coating are petroleum-based and as such are currently not biodegradable. [20]

4.2 Cork leather

The biggest producers of cork are Southern Mediterranean countries, mainly Spain and Portugal. Portugal owns about a third of the total cork tree area and produces about 50% of cork at the world level. The data from 2015. Refers to about 2,100,000 ha of cork oak forests and a cork production of about 201,000 t/year. [49]

The first step of the cork leather manufacturing process is cork harvesting (Figure 4.2.1). The cork tree needs to be 25 years old before it can be harvested for the first time, but the first harvest is not usable. After the first harvest, the bark of the cork is removed every nine years. The material can be used for textile purposes after the second harvest. [29]

Figure 4.2.1 Cork harvesting [50]

Once the cork bark arrives in the factory, it is boiled in water to make the cork cells expand and make it easier to handle during processing. The boiling consists of immersing the cork, for approximately 1 h, in boiling water, in big metal tanks. This operation aims to remove dirt, insects, and other impurities, to extract contaminating products, to decrease porosity and to render the planks flat, softer and more flexible, and therefore easier to work. [51] There are no harsh chemicals such as formaldehyde used in this process. [52]

The next step after boiling of the cork, is that the cork is left to ripen in warehouses for days or even weeks. Finally, the edges are cut to make the planks rectangular and a supervisor inspects and selects them according to thickness and quality, considering the flexibility, homogeneity, colour, evenness, and natural defects. Cork leather is produced from very fine laminated sheets of natural cork or agglomerated cork, which is glued on a textile or paper base. Usually, the thickness that is suitable for cork leather is 50–500 µm. [51] Cork is shaved down into very thin sheets, approximately the same thickness as tissue paper. To make the cork durable, the sheets are then glued to a cotton, cotton and polyester blend or polyurethane backing. There are different ways how pieces of cork are glued onto the backing, it all depends on the design. [52]

And while cork is naturally resistant to water and dust, usually some coating of sealant, which is non-toxic and non-environmentally-harming, is applied to the cork in the final step of production to keep it from getting dirty and make it easier to clean. [52]

4.3 Fungi leather

MycoWorks is a startup in San Francisco, California that produces a mushroom-based leather alternative. This material is a composite of mushroom mycelium and cotton cellulose. The current manufacturing process uses minimal chemical additives, using only small amounts of water and polyethylene glycol (PEG), and therefore has a relatively low carbon footprint, with the potential for a carbon-negative manufacturing process with some refinement. This production process works well for the current manufacturing scale, in which sheets ranging from one by one foot to sheets of several feet are manufactured. [53] Sophia Wang, the CEO and co-founder of the Mycoworks with material samples can be seen in Figure 4.3.1.

Figure 4.3.1 Sophia Wang, CEO, and co-founder of Mycoworks [54]

The first step of manufacturing the MycoWorks minimum viable product (MVP) is to seed Ganoderma lucidum spores onto sheets of felted cotton. The Ganoderma mycelium fibres grow among the cotton fibres and form a composite material which is then harvested. [53]

The current post-harvesting process has four steps: soaking, drying, plasticizing, and mechanical working. The purpose of the soaking and drying steps is to ensure the material has uniform moisture content throughout. Polyethylene glycol 400 (PEG 400), a hydrophilic low molecular weight polyol, is applied and maintains pliability by ensuring that the internal moisture does not evaporate. Lastly, the material is manipulated mechanically to produce the appearance of leather. [53]

The major advantage of MycoWorks' manufacturing methods is that they are able to alter several variables in the developmental process in order to fit customers' specifications. For example, one can alter the concentration of nutrients, type of nutrients, timing in which nutrients are provided as well as adjust the surrounding light, humidity, or gas levels. [54]

5 TRADITIONAL LEATHER GOODS

Historically there have been a really wide variety of leather products, such as leather boats known as coracles (still in use in Tibet), leather bottles, and leather armour. Over the centuries categories of leather products have changed considerably. The overall demand for leather products has not dropped and the mechanisms that drive the market for leather and its' products come down to population growth and per capita disposable income. Leather shoes are a rather basic purchase, but most of the other goods have to do with the growing wealth of consumers. [55]

It is estimated that globally the demand for genuine leather goods going to grow at a CAGR of almost 5 per cent in 2021, and bags and accessories would be the fastest growing category. It is predicted that the handbag segment would grow rather significantly, due to factors such as the rise in the working women population and the increasing purchasing power of many consumers. In 2018 the revenue in the bags and accessories segment was US$74,919m. By the year 2022, the number of users is expected to amount to 1,334.3m. [56]

Table 5.1 below are brought out the changes in the consumed amount of leather in different product sectors. The most significant fluctuations have been in the clothing category, where between 1970 and 1995 was a huge rise from 5% to 17.8%, later years the consumed amount has gone slightly down again. In the upholstery and vehicle categories has been a significant rise, as in upholstery sector numbers went from 5% in 1990 to 13.5% in 2010, and in the vehicle sector from 1.6% in 1990 to 8.2% in 2010.

Table 5.1 Genuine leather end uses based on square feet consumed in main product sectors [56]

Year	**Footwear sector, %**	**Clothing sector, %**	**Gloves Sector, %**	**Leather goods Sector, %**	**Upholstery Sector, %**	**Vehicles sector, %**
1970	50-70	3-5	3-5	15-20	N/A	N/A
1990	67.9	12.4	4.3	8.8	5	1.6
1995	62.6	17.8	4.2	8.7	4.8	1.9
2000	58	14.6	4.3	9.4	8.8	4.9
2005	55	11.4	4.4	9.2	13.0	7.0
2010	53.3	11.4	4.3	9.1	13.5	8.2

There are many product categories that have been traditionally leather made due to the good properties and quality of genuine leather, therefore it is needed to develop leather-like materials that could compete with real leather while being more sustainable and environmentally-friendly.

5.1 Footwear

Worldwide the leather footwear market size in 2018 was USD 166.53 billion and it is expected to increase with a CAGR of 2.8% from 2019 to 2025. This growth would be related to the increase of working-class population and rising income, also a successful retail e-commerce sector, and a growing fashion trend in business wear. Leather shoes are popular due to their durability and elegant look, furthermore, real leather is preferred for its breathability which cools down the feet and avoids causing unpleasant odours. [57]

There are no officially recommended values for leather shoe material characteristics, and tests conducted depend a lot on the type of footwear. For example, boots that are made to perform well during winters are tested for salt. Commonly the material is also tested for colour fastness, durability, and water resistance.

5.2 Bags, wallets, luggage

Global handbags market is on the rise and an important contributor for that growth is a brand awareness of luxury bags as a fashion symbol. This growth is biggest among adults in developing countries such as India, China, and Brazil and another big contributor is a rising female workforce on a global level. Genuine leather bags had the biggest share of the market in 2018 with 48.5% of the global revenue. Genuine leather is preferred due to better quality and durability, and also luxury goods such as leather bags are desired as a status symbol. [58]

There are no officially recommended values for leather handbag material characteristics, but common tests for handbags include testing the strength of straps and strap fastenings and different colourfastness tests to measure the risk of colour transferring to clothing. Also, water spotting tests can be performed to evaluate the effect of water, also light rain could have on a material appearance.

5.3 Upholstery

Leather is known to be luxury material for upholstery and it is still used for clients all over the world, but for the upholstery market, leather-like alternative materials are increasingly popular. Faux leather furniture is made using synthetic or artificial leather and common products include chairs, sofas, and headboard upholstery. Faux leather furniture is commonly advertised as vegan leather furniture and it consists of tightly woven microfibres which helps to increase durability, also those materials are created to prevent degradation and the damage that can happen due to accidental spill of animal saliva or beverages. Faux leather is easy to clean, and damp towels are enough to remove stains and other marks. Often the faux leather material is made so that it does not crack when exposed to sunlight and also such furniture has waterproof features that make it suitable for outdoor furniture. Rising consumer awareness about animal rights and the environmental consequences of genuine leather manufacturing promotes the purchase of faux leather furniture. Leather alternatives avoid the unnecessary killing of animals. [59]

There are specific recommended values in the standard Leather - Upholstery leather characteristics - Guide for selection of leather for furniture (EVS-EN 13336:2012) for the essential characteristics of leather material suitable for manufacturing the upholstery furniture which are shown in Table 5.3.1 below.

Table 5.3.1 Selection of main characteristics of leather upholstery and automobile interior with recommended values according to EVS-EN 13336:2012 [60]

Main Characteristics	**Test method/ standard**		**Recommended values**		
			Nubuck, Suede, Aniline	**Semi-aniline**	**Coated, pigmented, etc**
Tear load, average	EN ISO 3377-1		>20 N	>20 N	>20 N
Colour fastness to rubbing	EN ISO 11640 EN ISO 11641	Dry felt	50 cycles, ≥3 grey scale	500 cycles, ≥4 grey scale	500 cycles, ≥4 grey scale
		Wet felt	20 cycles, ≥3 grey scale	80 cycles, ≥3/4 grey scale	250 cycles, ≥3/4 grey scale
		Artificial perspiration	20 cycles, ≥3 grey scale	50 cycles, ≥3/4 grey scale	80 cycles, ≥3/4 grey scale
Colour fastness to artificial light	EN ISO 105-B02		≥3 blue scale	≥4 blue scale	≥5 blue scale
Colour fastness to water spotting	EN ISO 15700		≥3 grey scale	≥3 grey scale	≥3 grey scale
Cold crack resistance of the finish	EN ISO 17233			-15 ºC	-15 ºC
Burning behaviour	EN ISO 1021-1 EN ISO 1021-2		Pass	Pass	Pass

5.4 Automotive interior

Genuine leather has been dominating the global automotive interior leather market in terms of value but synthetic leather is rapidly gaining popularity. Genuine leather is preferred in high-end vehicles by companies such as Rolls-Royce Motor Cars Limited, Land Rover, and Bayerische Motoren Werke AG, despite the availability of cheaper artificial or faux variants. [61]

Synthetic leather usage is on the rise due to the increase in consumer disposable income, steady technological advancements, and better product performance as compared to other leather alternatives. Synthetic/artificial leather materials have cheaper production costs and easier manufacturing process. The production process of manufacturing natural leather, especially tanning, leads to pollution of nearby surroundings. Strict environmental laws and government regulations also contribute to the rising demand for synthetic leather. [61]

There are specific recommended values for some of the essential characteristics of leather suitable for manufacturing the automobile interior and those are the same as for the upholstery furniture brought out in Table 5.3.1.

5.5 Clothes

Genuine leather as a clothing material has a long history, but nowadays the most common apparel categories are jackets, skirts, pants, dresses. Leather material is used for both- innerwear and outerwear assortments, although due to this materials' thickness and warm-keeping properties it is more commonly seen as a good material for a colder climate. Commonly faux leather is used for clothing as it is much cheaper and has good characteristics.

There are specific recommended values given in standard Leather - Guide to the selection of leather for apparel (excluding furs) (ISO 14931:2015) for the essential characteristics of leather suitable for manufacturing the clothes. Some of the main ones are brought out in Table 5.5.1 below.

Table 5.5.1 Selection of essential characteristics of leather apparel with recommended values according to EVS-EN ISO 14931:2015 [62]

Essential characteristics	**Test method/ standard**		**Recommended values**
Colour fastness to light	ISO 105-B02		Aniline, nubuck, suede ≥3 blue scale Other finishing ≥4 blue scale
Colour fastness to rubbing	ISO 11640	Dry felt	20 cycles, ≥3 grey scale
		Wet felt	10 cycles, ≥3 grey scale
		Artificial perspiration	10 cycles, ≥3 grey scale
Colour fastness to water spotting	ISO 15700		≥3 grey scale
Colour fastness to dry cleaning	ISO 11643		≥3 grey scale No finishing lost
Tear strength	ISO 3377-1		>20 N
Flexing resistance	ISO 5402-1		Aniline ≥ 20 000 cycles Other leather ≥ 50 000 cycles
Chromium VI content	ISO 17075		≤ 3mg/kg
Formaldehyde content	ISO 17226-1		≤ 150 mg/kg

6 PROCESSING TECHNOLOGY AND EQUIPMENT

6.1 Cutting technologies and equipment

The main technologies that are applied for leather cutting include slitting knives, die press techniques, manual cutting, and laser cutting.

6.1.1 Knives and scissors

The knife is the main tool for cutting leather for handmade products in small scale manufacture. For thicker leathers that weigh 7 ounces (about 198 grams) or more the most commonly used knife type is cobbler's knife, also known as shoemaker's knife. This knife can be used for cutting thick leather or to reduce the thickness of any kind of leather. Other common knife types used for cutting the leather are round head knife used for cutting heavy leather, bevel point knife used for reducing the thickness of leather and to trim the edges, skiving knife used to reduce the thickness of leather, skife knife also used for reducing the thickness, and cutter or cutting knife with a blade that is shaped in 60- or 90-degrees angle. [63]

Scissors are also very typical tools used for cutting the leather and there are two main types- leather scissors and leather shears. Leather scissors have serrated blades and leather shears are plain scissors with longer blades. [63]

6.1.2 Die-cutting

The die-cutting process is a cutting technique where the die is used to shear webs of low-strength materials, such as rubber, fibre, foil, cloth, corrugated fibreboard, paperboard, plastics, pressure-sensitive adhesive tapes, foam, and sheet metal. In the leather industries, this process is also known under the term clicking and the machine may be referred to as a clicking machine. There are two main types of die-cutting- rotary die-cutting (also known as gasket die-cutting) and flatbed die-cutting. [64]

The die-cutting is a process where shapes are cut from sheets of material by using a shaped knife and pressing the edge into one or several layers of sheeting. The dies used in the process are commonly known as steel rule dies. After the cutting process is complete, hydraulic or mechanical presses are used to apply pressure. [64]

6.1.3 Laser cutting machine

The laser has been used for cutting in the apparel industry since the nineteenth century and is still a rather new approach in the textile sector, but the usage of laser technology has grown significantly during recent years due to its advantages such as flexibility, high production speed, possibility to cut complex geometries, easier cutting of customized parts, and fewer leftovers of leather which make laser cutting economically attractive for leather cutting industry. [65;66]

A laser is light amplification by stimulated emission of electromagnetic radiation, produced by the atoms that are promoted to higher energy states. This laser is then being additionally amplified in a suitable lasing medium with the help of mirrors, and the final laser is emitted from the equipment as a stream similar to light. The colour of this laser beam depends on its wavelength. Laser light has four fundamental characteristics, which are intensity, coherence, monochromaticity, and collimation. The laser beam is characterised with intensity and power that can be controlled with excellent precision. It is possible to focus the laser beam on an object at a specific angle depending on the application and desired outcome. The laser can be used to cut very different types of materials ranging from flexible fabric to rigid and strong metal. [65]

If the laser cutting parameters are properly chosen, then this technology provides stable cutting quality even with complicated designs and makes it possible to utilize leather material in the economically best way. [66] Furthermore, laser technology is suitable for individual designs, prototypes, and small-scale products and offers high speed, high precision, and repeatability and can even be used to fabricate three-dimensional patterns [67]. Laser cutting can be very beneficial due to its possibility to change production from one product to another only by changing geometry without a need to change the whole cutting tool. But there are also some disadvantages of laser processing such as high initial investment costs and some running costs due to maintenance and required gas supply for the laser. It is also important to keep in mind that this kind of technology needs a higher level of operator’s expertise due to more complicated machinery. [66]

CO2 laser cutting and engraving technology are used broadly to cut or engrave the leather materials, typically shoes, bags, and cloth. Usual cutting speed can reach 5 - 30 mm per second, the engraving speed may reach 600 mm per second. [66]

The laser cutting machine has two main productivity aspects: nesting and cutting sequence. Nesting is a process of the positioning of parts to be cut on given material with the main aim to minimize waste, and generally, it is done based on operator experience, which makes it challenging. There are different nesting software that could be used to enhance material utilization and improve the flexibility of the production. Cutting sequence targets the optimal cutting procedure for minimum cycle time, and therefore the objective is to find the shortest path to accomplish cutting procedure. There are different challenges that occur with nesting and cutting sequence when using the real leather due to the irregular shapes, contours, and quality zones of this material. [66]

6.2 Joining methods and equipment

When joining materials together it is important to consider the type and nature of substrates to be bonded, aesthetic appeal, strength and the expected stresses that the joint will face in service, durability and the expected environments that the joint will face in service, comfort in wear, equipment availability, and cost. [68] Alternatives to traditional sewing using needle and thread include bonding and welding. [69]

6.2.1 Sewing

Seams produced by traditional sewing offer high strength and low stiffness, which makes it an ideal joining method for most of the common textile products. Traditional sewing has its disadvantages such as discontinuous joints producing perforated seams, sewing thread deteriorating over time, thicker material at the point of joining, and production speed limitations. [68]

Seams of the product have to be chosen following the product type and purpose, and therefore has to combine required standards of appearance and performance whilst being economically efficient. Seams are categorized into specific groups. [69]

- Class 1 seams, also known as superimposed seams are generally made on two or more piles of fabric laid upon one another in the same orientation and those layers are usually stitched together near the edge of the fabric with one or more rows of stitching. Final stitching rows may be achieved by sewing simultaneously or consecutively and seams may be reinforced with fused or stay tapes along the length of the seam. [69]

- Class 2 seams, also known as doubled lapped seams have good strength and are used extensively in many areas of apparel, outwear, and also on high-performance products. [69]

- Class 3 seams, also known as bound seams are used in many areas of product manufacture and produce a neat seam on the face of the fabric. These seams are used for a big variety of applications including luggage and tent manufacture. [69]

- Class 4 seams, also known as flat seams are produced with a minimum of two plies of fabric butted together at the raw edge on the same level. To create these seams a minimum of two rows of stitching are conducted simultaneously and are joined on one or both surfaces. These seams are often used in knitwear to reduce bulkiness around the join especially, very common for underwear. [69]

Hand-stitching is also very common for leather materials and there are various stitch types and techniques used for hand-crafted products. The most suitable thread for hand-stitching is a high-quality linen thread, and threads are coated with beeswax before the use. [70]

6.2.2 Welding

Welding process is not suitable for genuine leather but it can be used for artificial leather covered with PVC and PU. Thermal welding is a process where the joining and sealing of thermoplastic garment materials are achieved without the use of adhesives or other additional means such as sewing, staples, or other fasteners. The term "welding," can also be referred to as using heat-activated adhesives as a welding process although, in the conventional use the thermal welding is done without an additional adhesive and the process commonly uses the substrate itself as the adhesive. [68] There are different methods for welding, but all of them include thermoplastic material being joined by raising the temperature of the substrate to a level that melts the fabric at the interface of the two plies. The pressure is applied in a controlled manner to promote the flow of one material into the other and upon cooling a weld bead is formed. [69]

Conventional thermal welding is a thermal process that requires the melting of fabric materials, but commonly a separate heat-activated adhesive material is used. Heating necessary to melt the material is achieved by direct contact of the fabric with a heated-tool surface or hot air. This technology is suitable for woven or nonwoven fully or partially synthetic fabrics which have thermoplastic components that are chemically and physically compatible when fused. [68]

Advanced thermal welding technology although otherwise similar to conventional thermal welding uses systems where heating is achieved by indirect contact of the fabric with a source such as ultrasonic horn, electromagnetic field, or laser. In this process commonly, a separate heat-activated adhesive material is used between joined material layers. This technology is most suitable for woven fully or partially synthetic fabrics which have thermoplastic components that are chemically and physically compatible when fused. [68]

6.2.3 Adhesive bonding

Adhesive bonding is a joining method that needs a separate material at the joint interface, which binds either chemically or mechanically to the substrate. There are different types of adhesives used in this process and they may be chemically or thermally reactive or may bond on evaporation of a carrier, which could be either water or solvent. Those adhesives that are chemically reactive solidify mainly by a chemical reaction of one or more components in the adhesive formulation. Solvent welding cementing processes or solvent-borne adhesives have stricter environmental, safety, and health concerns and regulations due to their hazardous nature. Therefore, safer waterborne adhesives and heat-activated adhesives are replacing solvent-based adhesives in many applications. [68]

Most woven and non-woven synthetic or natural fabrics independent of synthetic fibre content are suitable substrates for adhesive bonding. Adhesive bonding is also suitable to join garments to nontextile accessories such as glitter and foil. The specific technology and form of adhesive (liquid, film, powder) will be determined by the type of materials and adhesive and also by the production speed that is required. [68]

Adhesive bonding is commonly used with leather materials as it can be used to either bond panels permanently, or to hold them temporarily before completing the sewing of thonging process. In general, adhesives for leather can be used for wet-stick bonding, where the adhesive is applied wet to one or both surfaces and layers are joined immediately, or dry-stick bonding, where the adhesive is applied to both surfaces but then allowed to dry before joining the layers together. [70] Also, different fusible double-sided tapes and textiles can be used between layers of leather or leather and some other material to join them together.

6.3 Customization methods

6.3.1 Embroidering

Embroidery is the decoration of woven or knitted textile fabrics or other surfaces, for example, leather, through the application of threads or other decorative objects, such as beads, cords, applications, by sewing them in or on in an arrangement designed to achieve a pattern on the ground fabric. [71] Embroidery as a decorative addition can be seen on a lot of different products and materials. Embroidery has also been previously used on Piñatex® leather by brand Allure Sauvage from Switzerland, and there can also be found some examples of embroidery on cork fabric, but generally only hand-stitched.

Embroidery can be made by hand or by special embroidery machines. There is a wide variety of needles and threads that can be used for different types of textiles, and also a lot of different decorative stitches that can be done by hand, such as straight stitch, blanket stitch, chain stitch, herringbone stitch, cross-stitch, seeding stitch, French knot, couching, smoking, back stitch, stem stitch, satin stitch, and buttonhole stitch. [72]

Computerised embroidery is done using a special sewing machine. The design that is used can be made on the machine itself using the machine's built-in memory or on a PC, using special software that is compatible with that sewing machine. The design is then exported to the machine from the computer via direct link or by using some additional device. [72]

The typical procedure for creating embroidery design:

- image selection,
- importing the image into the design software,
- digitizing the image using the software,
- applying the machine stitches,
- setting design parameters, stitch size, etc.,
- saving the design,
- Sending the image to the sewing machine. [72]

6.3.2 Engraving

In general, engraving is the practice of incising a design, which could be a pattern, picture or text on to a surface that is commonly hard and flat, by cutting grooves into it. [73] Engraving can also be done on leather and some textile materials and is somewhat similar to etching, which involves the use of acid or a similar chemical for imprinting the material [74].

The laser can be used to cut various textile materials, knitted fabrics, meshworks, woven fabrics, nonwoven fabric, and felts, but it can also be used for engraving. Laser technology is more commonly used in technical textiles for filters, upholstery, heat protection fabrics, and textile components in the automotive industry or sails. [75] In more commercial applications, different pictures, flower patterns, and personalized signatures can be engraved on leather shoes, bags, wallets, belts, sofas, and clothes, therefore greatly increasing the added value of those products. Furthermore, laser engraving can be used to create an embroidered pattern in the fabric by colour fading and burning the fabric surface. [74]

Laser engraving is the practice of using lasers to mark an object. The technique is very complex, and generally, a computer system is used to drive the movements of the laser head. The technique does not involve machinery parts, that contact the engraving surface and wear out which is an advantage over alternative engraving technologies where bit heads have to be replaced regularly. [74] Very precise and clean engravings can be obtained with laser technology without tearing the fabric surface. This method is good for high production rates, but it is important to acknowledge that marks produced by laser engraving are permanent and therefore can't be fixed or changed later. Implementing laser technology shows versatility in material selection and is generally faster than the other methods used for product imprinting. [75] Laser cutting machine can cut through thin materials as well as engrave on them, which makes it multifunctional. Laser engraving can be used for different purposes: to engrave the printing screens, for hollowing, for creating pattern buttons, to engrave leather, denim, etc. Generally, sealed carbon dioxide lasers are preferred for laser engraving due to their low cost. Accuracy of the results depends upon laser stability, complete control of pulse duration and energy, dynamic auto-focus, and power on demand. [74]

6.3.3 Printing

Digital printing makes it possible to create unique products that no other technique does unless created entirely by hand. In the leather printing industry, the most used industrial inkjet inks include UV ink, polymer latex ink, and dye sublimation. To guarantee the best results, the ink must become part of the surface material and texture. For the large pieces of leather, the best machinery choices are flatbed printing systems. [76]

Inkjet printing is a printing technique that essentially involves the ejection of a fixed quantity of ink in a chamber, from a nozzle due to a sudden, quasi-adiabatic reduction of the chamber volume that results from piezoelectric action. A chamber filled with ink is contracted by using an external voltage and this causes a shockwave in the liquid, and results in a liquid drop to eject from the nozzle. This drop impinges on the substrate affected by gravity and air resistance, then spreads under momentum acquired in the motion, and causes a surface tension aided flow along the surface. The ink dries through solvent evaporation. [77]

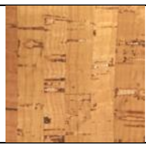
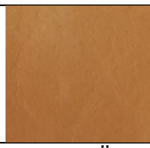
Currently the main application for leather digital printing is the apparel industry, but as international modern-minded interior design firms apply the technology, more printed leather designs on the furniture will begin appearing. [76]

7 MATERIALS AND METHODS

7.1 Materials

In table 7.1.1 are descriptions of the four materials that are going to be tested to evaluate if those chosen leather alternatives are suitable replacements for real leather. The more detailed material specification for used PU covered fabric is given in Appendix 20.

Table 7.1.1 Materials used for testing

	Piñatex® Original Charocal	**Cork material**	**PU covered fabric**	**Vegetable-tanned leather**
Picture				
Place of purchase	Piñatex® by ananass anam web store	MB Cork web store	Kangas ja Nööp store	Skineks OÜ
Price per dm²	0.32 EUR	0.25 EUR	0.09 EUR	0.66 EUR
Material configuration	72% PALF 18% PLA 10% PU	**Surface:** 100% cork **Backing:** 63% CO 37% PL	40% PU 30% VI 30% PL	100% leather
Fabric width, cm	155	135	140	-
Fabric thickness, mm	1.6 ± 0.1	1.0	N/A	1.3
Fabric weight, g/m²	475	N/A	320	N/A

7.2 Materials testing methods

In this chapter are descriptions of different testing methods and standards common for leather good materials in general or specifically necessary for testing materials used for handbags. Tests were conducted at Tallinn University of Technology laboratory of textile technology. Test results given in further subchapter make it possible to compare genuine leather with its' alternatives- Piñatex®, cork material, and PU covered fabric.

Piñatex® material and cork material are planned to be used for three sample envelope bags to test their processing qualities in manufacture. In figure 7.2.1 are the first designs for the bags. All bags will have Piñatex® material and cork material details mixed to give contrast and enable different customization possibilities.

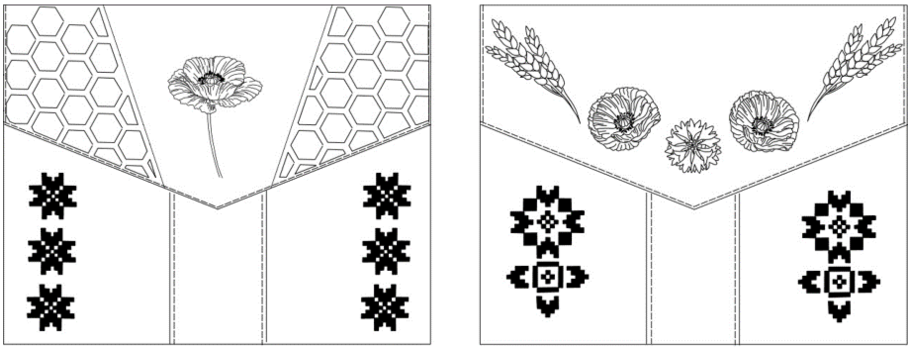


Figure 7.2.1 First designs

7.2.1 Composition

Cork material was tested because the information that was obtained with the material purchase did not seem to be complete as there was no information about the adhesive used between the cork and fabric layers. To test the adhesive layer of the material FTIR analysis method was used. To find out if the information about the backing material configuration was accurate microscopy and quantitative chemical analysis methods were chosen.

FTIR

Fourier Transform Infrared Spectrometers (FTIR) are widely used for the identification of materials in organic synthesis, polymer science, pharmaceutical industry, and food analysis. The main idea behind FTIR analyses is that every molecule has slightly different vibrational modes from all the other molecules, and therefore the infrared spectrum of a given molecule is unique and can be used to identify that molecule. [78]

The three main components of the basic spectrometer in an FTIR system are radiation source, interferometer, and detector. [79] IR radiation is obtained from the thermal emission of an appropriate source, commonly an inert solid heated electrically in the range from 1,000°C to 1,800°C. [80]

In FTIR spectroscopy, the most commonly used interferometer is a Michelson interferometer. The incoming beam of light is split inside an interferometer to two beams so that the paths of the two beams are not identical. One beam goes to the internal fixed mirror and the other one goes to a moving mirror. Following the reflection, the Michelson interferometer recombines the two beams again to produce an interference pattern and direct them to the detector. Then, it is necessary to perform a mathematical transform operation on the data to make it presentable in a usable interference. [79]

In this practical work was used an Interspec 200-X from the company Interspectrum (Figure 7.2.1.1). The test specimen was cut out and cleaned with ethanol. Then, the specimen was put in the spectrometer. Graphics obtained from the test were compared to the Spectral Library database to find correlation and identify the material.

Figure 7.2.1.1 Interspec 200-x machinery

Microscopy

The basic light or optical microscope consists of a single lens, a magnifying glass, and uses visible light as a source of illumination. The microscope that consists of more than one glass lens in combination is a compound microscope and includes a condenser lens, that focuses the light from the light source at the specimen, the objective lenses are the lenses that face the object and the eyepiece lenses are the ones closest to the eye. The objective lens produces the magnified image and is available in different varieties, such as 4x, 10x, 20x, 40x, 60x, 100x. [81]

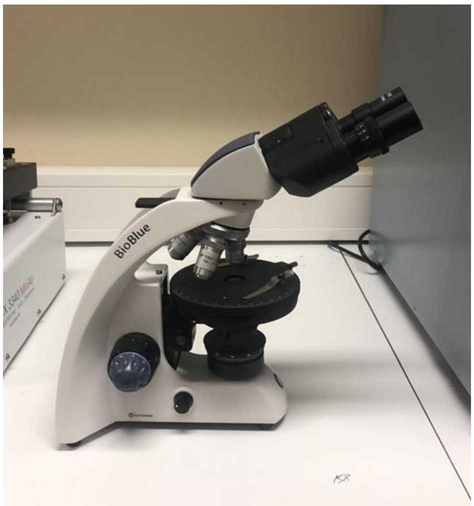


Figure 7.2.1.2 Optical microscope by BioBlue

In this test an optical microscope (Figure 7.2.1.2) is used to see if there are any cotton fibres visible among the polyester fibres. Separate samples were prepared for fibres taken from warp yarns and to fibres taken from weft yarns. For preparation, fibres are taken from the material using tweezers and then placed on a glass slide. When the fibres are mounted in a suitable place a drop of distilled water is added on the fibres and then the specimen is covered with glass slip. Excess water is carefully removed using a paper towel.

Quantitative analysis

The percentage of the composition was tested by a chemical quantitative analysis method which is based on the selective solution of the individual components. When the component that is needed to remove is dissolved the insoluble residue is weighed, and the proportion of the soluble component is calculated from the loss in mass. If sulfuric acid is applied to a textile made of polyester and cotton, the cotton part dissolves but the polyester does not. Therefore, this method can be used to clarify the mix ratio of polyester and cotton. [82]

Figure 7.2.1.3 Test samples during heating

The test was done with the uncoated fabric area that was cut from the edge of the fabric. The steps for conducting the test are the following:

- Cutting the test specimen. The test specimen has to weigh at least 1.0 g and this sample piece is divided into two samples, both have to weigh approximately 0.5 g.
- Oven-drying of the samples.
- Weighing sample pieces of fabric and crucibles and marking them for later identification.
- Adding 100g of 75% to samples.

- Heating samples in a water bath in a way that the temperature stays close to 50 °C but does not raise over 55 °C for an hour (Figure 7.2.1.3).
- Collecting and washing of the residue.
- Drying and weighing of the residue.
- In the end, the mass is expressed as a percentage of the dry mass of the mixture, and the proportion of dry cellulose fibre is found by difference. [82]

$$m_{PE} = m_{fw} - m_{fc}$$
$$m_{CO} = m_{is} - m_{PE} \tag{7.2.1.1}$$

Where m_{is} – Initial weight of the sample, g,
m_{fc} – Weight of the filter crucible, g,
m_{fw} – Final weight with filter crucible, g,
m_{PE} – Mass of polyester in the sample, g,
m_{CO} – Mass of cotton in the sample, g.

Mass percentage is calculated using the following formula:

$$W\% = \frac{mass}{total\ mass} \cdot 100\% \tag{7.2.1.2}$$

7.2.2 Mass per unit area

Three different standards were used for testing mass per unit area of cork material, PU coated fabric, Piñatex® material, and real leather. The test was conducted according to standard EVS-EN 12127:2000 for cork material and PU coated fabric, but the Piñatex® material was tested according to standard EVS-EN 29073-1:2000, that is suitable for non-woven materials. The test with real leather is conducted according to standard EVS-EN ISO 2420:2017.

Standard ISO 12127:2000

Standard Textiles - Fabrics - Determination of mass per unit area using small samples (ISO 12127:2000) describes methods for the determination of the mass per unit area using small samples in the standard atmosphere and/or oven-dry for testing, and this method is suitable for woven and knit materials. The small-scale test pieces that are used for this test method have to be previously stored for at least 24 hours under standard atmospheric conditions. According to ISO 139, the standard atmospheric conditions are relative humidity of 65 ± 4% and a temperature of 20 ± 2 °C. [83]

The mass of the known area is divided by the unit area and is expressed in grams per square meter. When cutting test specimens from the material to be tested, areas with folds and wrinkles, and other areas not representative of the fabric should be avoided. [83]

First, 5 test pieces are cut from different places on the fabric. They are then left under the normal conditions of the tests until measured the next day. As the specimens are cut with scissors for this test, the length and the width of the specimens are measured from three different places, and the mean lengths and widths and the areas of the test pieces calculated. All test specimens are weighed and their average weight is calculated. [83]

The formula for the calculation:

$$M = \frac{m \cdot 10000}{A}, \qquad (7.2.2.1)$$

Where M – Mass per unit area, g/m^2,

m – Mass of the specimen, g,

A – Area of the specimen, m^2. [83]

Standard ISO 29073–1:2000

Standard Textiles - Test methods for nonwoven - Part 1: Determination of mass per unit area (ISO 29073-1:2000) describes a method for measuring the area and mass of a non-woven test piece and calculating its mass per unit area in grams per square metre. [84]

Three test specimens with an area of at least 50 000 m^2 have to be cut using a razor blade. The tested area should not be smaller due to the anisotropy of non-woven materials. Balance that is used for determining the mass has to have an accuracy of ±0.1 % of the determined mass. [84]

The mass per unit area of each piece is calculated as the mean value in grams per square metre. [84]

Standard ISO 2420:2017

Standard Leather -- Physical and mechanical tests -- Determination of apparent density and mass per unit area (ISO 2420:2017) describes a method for determining the apparent density and the mass per unit area of leather and is suitable for all types of leathers. [85]

This test needs three specimens. The square-shaped specimens have to have measured distances AC and BD, where A, B, C, and D, are the midpoints of each side within 0.5 mm by using Vernier callipers to the nearest 0.05 mm (Figure7.2.2.1). Distances have to be measured from grain surface and flesh surface and then their arithmetic mean is going to be calculated. [85]

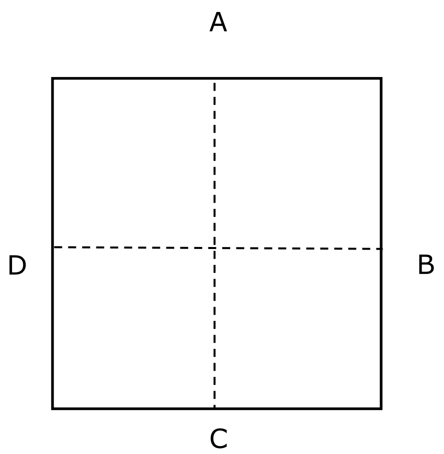


Figure 7.2.2.1 Test specimen measurement distances

For the cuboid test specimen, the mass per unit area m_a, in grams per square metre is calculated as

$$m_a = \frac{10^6 \cdot m}{a \cdot b} \tag{7.2.2.2}$$

Where *a*- Mean distance AC of the test piece, mm,
b- Mean distance BD of the test piece, mm,
m- Mass of the test specimen, g. [85]

7.2.3 Tear force

Standard Leather - Physical and mechanical tests - Determination of tear load - Part 1: Single edge tear (ISO 3377-1:2011) specifies a method for determining the tear strength of leather using a single edge tear also known as trouser tear. This test method is suitable for all types of leather. [86]

The principle of the test method given in standard ISO 3377-1:2011 states that a rectangular partially slit test specimen is pulled so that a tear is propagated from the end of the slit, and the mean force of the separation motion is recorded. [86]

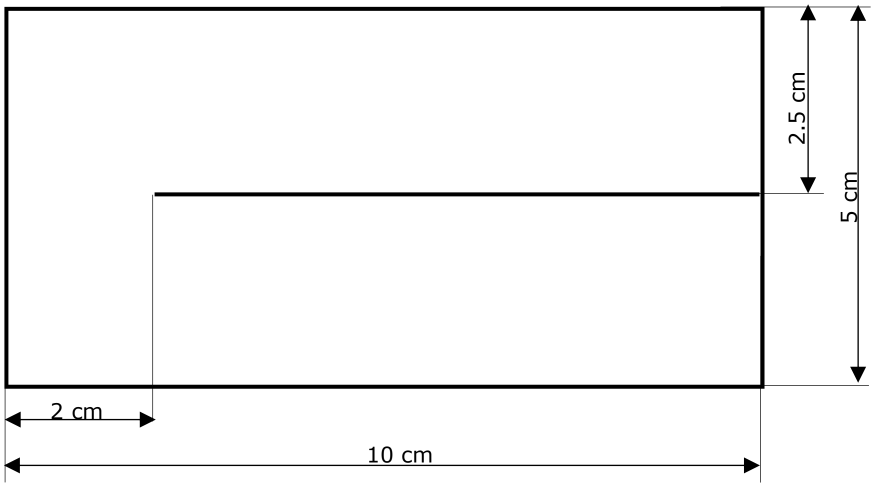


Figure 7.2.3.1 Test specimen measurements

For this test, six test specimens of each material were used. According to standard three test specimens are cut with the longer side parallel to the backbone and three test specimens with the longer side perpendicular to the backbone. Cork leather alternative and PU covered fabric were cut out three test specimens longer side parallel to the warp direction and three test specimens with the longer side parallel to weft direction. Piñatex® test specimens were cut three pieces parallel to the length of the non-woven material and three pieces parallel to the width of the non-woven material.

When testing the samples, the jaws of the tensile testing machine Instron 5866 (Figure 7.2.3.2) had to be at the distance of 50 mm of each other. Test specimens had to be clamped in the machine so that the long edges of the test specimens were parallel to the testing direction of the machine. [86]

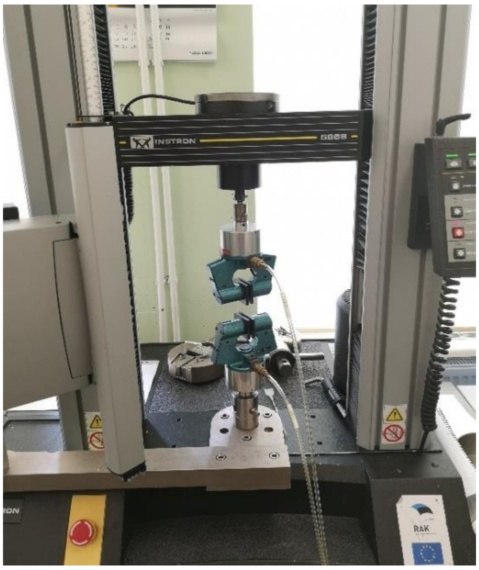


Figure 7.2.3.2 Tensile testing machine Instron 5866

The testing of the specimen lasts until it is torn apart, and the force-extension plot is recorded. The tear load of the test piece is determined as the arithmetic mean of the forces on the peak trace. [86]

7.2.4 Air permeability

According to standard Textiles - Determination of permeability of fabrics to air (EVS-EN ISO 9237:2000) air permeability is defined as a velocity of airflow passing perpendicularly through a test specimen under specified conditions of the test area, pressure drop, and time. [87]

The principle of the test method given in standard EVS-EN ISO 9237:2000 is following, the air rate of flow of air passing perpendicularly through a given area of fabric is measured at a given pressure difference across the fabric test area over a given time. [87]

This test was conducted using FX 3340 MinAir machinery (Figure 7.2.4.1). The pressure drop was 100 Pa, which is suitable for apparel fabrics and the test area was 20 cm^2.

Figure 7.2.4.1 FX 3340 MinAir machinery

The test specimen has to be mounted in the circular specimen holder on top of the test head, under the clamping arm with enough tension to eliminate wrinkles. Selvedges and areas with creases and folds have to be avoided. The test head can be closed by pushing the clamping arm down. Then, the locking lever will snap in place and the machine will start to force the air through the test specimen. The result is noted down when it is stable or almost stable. The test procedure has to be repeated 10 times. [87]

7.2.5 Abrasion resistance

According to standard Textiles - Determination of abrasion resistance of fabrics by the Martindale method - Part 1: Martindale abrasion testing apparatus (EVS-EN ISO 12947-1:2001), the Martindale abrasion tester uses a circular specimen with a defined load and rubs it against a standard fabric, which is used as an abrasive medium in a translational movement tracing a Lissajous figure. The specimen holder, which can be containing either specimen or abrasive medium depending on the method that is being used, is additionally freely rotatable around its axis perpendicular to the horizontal plane. [88] For testing leather materials the test procedure is slightly modified to use a ball plate underneath the specimen to have a better simulation of day-to-day usage. [89]

Apparatus and materials used:

- Martindale abrasion testing apparatus (Figure 7.2.5.1) and materials,
- Abrasion holder, with a diameter of 38 mm,
- Loading piece, with a pressure of 12 kPa,
- Mounting weight, with a mass of (2.5 ± 0.5) kg and the diameter of (120 ± 10) mm,
- Abrading fabric, with a diameter of 38 mm,
- Felt, with a diameter of 140 mm,
- Foam, with a diameter of 38 mm,
- Circular sample cutter or press knife, with a diameter of approximately 150 mm,
- Ball plate, with 37 steel balls. [89]

Figure 7.2.5.1 Martindale abrasion testing apparatus

This test method needs at least two test specimens of the same material and for the final result, the mean value is calculated. The steps for conducting the test are the following:

- Firstly, the abrading fabric backed with foam is fixed into the abrasion holder. The test set-up on the specimen table is the following: felt, ball plate, and on top them the leather specimen.
- Mounting weight has to be used while setting up the test specimen to ensure that no wrinkles are formed on the specimen surface. The correct positioning has to be checked before testing.
- Then the abrasion holder is mounted with the abrading fabric on the Martindale machine and the loading piece is added.
- If the apparatus is set-up correctly, then the first 100 rubs are carried out.
- After that, the abrasion holder with the abrading fabric is removed from the Martindale machine and the leather surface is visually assessed.
- The number of breakdowns of the surface has to be noted down. A finish breakdown is reached if the finish layer is completely damaged and the leather fibres are uncoated and clearly visible. To be precise in visual assessing a portable microscope can be used.
- The cycle of 100 rubs is repeated the same way until four or more places of finish breakdown have been created. [89]

7.2.6 Colour fastness to water spotting

The test was conducted according to standard EVS-EN ISO 15700:2000, Leather - Tests for colour fastness - Colour fastness to spotting water (ISO 15700:1998).

The principle of the test is following, two drops of distilled water are placed at separate spots on the leather, and then later the surface is visually evaluated. After 30 minutes, any surplus water is removed with filter paper from one of the drops and any physical effects are observed. The other drop is allowed to evaporate for 16 hours and the change in colour of the leather is assessed with the standard greyscale. [90]

7.3 Materials processing machinery

7.3.1 Laser cutting and engraving machine

Laser machine Bodor BCL-1309XU is a CO2 standalone laser cutting and laser engraver machine suitable for larger-scale projects, where feed through system allows for cutting of full-sized sheets (Figure 7.3.1.1). This machinery is available with a 100 W laser tube but it can be configured up to 150 W. [91]

This laser cutting machine has a feed through at the back and front of the machine, enclosed unit with door sensors for a safe environment, electric up-down worktable up to 320 mm, and a WFI connection for wireless file transfer. It also has LED internal lighting to monitor your progress and Red Cross positioning system for the laser head. This machinery has as possible options as the honeycomb table, rotary device, and automatic height adjustment. Compatible software are Illustrator, Photoshop, CorelDraw, AutoCAD, Solidworks, etc. [91]

Figure 7.3.1.1 Bodor BCL-1309XU laser engraving and cutting machine

Table 7.3.1.1 Bodor BCL-1309XU machinery main parameters [91]

	Bodor BCL-1309XU
Laser type	CO2 Sealed Laser Tube ,10.6 µm
Cooling type	Water Cooling
Workspace	1300x900 mm
Power	100 W
Max engraving speed	60000 mm/min
Max cutting speed	40000 mm/min

7.3.2 Embroidery machine

Texi Iris 10 is a small and compact, one-head, ten-needle industrial embroidery machine with a cylindrical arm (Figure 7.3.2.1). This machine has an automatic thread trimming system, auto thread break detection, built-in LED light, and also comes with an external thread winder. This machinery includes 4 hoops with measurements: 70 x 50 mm, 110 x 110 mm, 190 x 140 mm, and 310 x 210 mm. Machine work well with ZSK, Tajima, Barudan file formats (.dst, .dsb, .fdr). [92]

Figure 7.3.2.1 Texi Iris 10 machinery

This machinery has a 7'' touch panel which enables necessary functions, such as START, STOP key, auto thread trimming, colour change, frame move, embroidery status, and numerical keys for needle choice. It is possible to edit, erase, copy, and scale the design directly on the panel's screen and also to follow the progress of the embroidery in real time on the panel. [92]

Table 7.3.2.1 Texi Iris 10 machinery parameters [92]

	Texi Iris 10
Heads	1
Needles	10
Machine size	64 x 57 x 78 cm
Embroidery area	310 x 210 mm
Max speed	1000 stitches / min
Motor	150W power-saving servo motor
Voltage	220-240V / 50-60 Hz

7.3.3 Textile Printer and printer hot-press

Textile printer GT-341 is a modular garment and T-shirt printer with CMYK and it is a great choice for small production as a starter model for printing on whites and lights. This machinery features up to 1200dpi printing, therefore also allowing photographic quality printing of images. Printing can be done directly from the USB flash drive as this model has USB flash drive compatibility. GT-341 has a front-loading ink cartridge system that is designed to provide consistent print quality and also more compact footprint. [93]

Figure 7.3.3.1 Brother GT-3 Series textile printer

Table 7.3.3.1 Textile printer GT-341 main parameters [93]

	Textile printer GT-341
Type	Direct Inkjet Garment Printer
Print heads	4
Ink type	Water-based pigment ink
Ink colour	CMYK
Ink cure	Heat press or conveyor oven/dryer
Printing area	14" x 16"
Printed substrate	100% cotton; 50/50% cotton/polyester blends
Suggested PC applications	Adobe® Photoshop®, Adobe® Photoshop® Elements, Adobe® Illustrator®, CorelDraw®, Corel® PaintShop™ Pro

The MAXX® Clam Heat Press by Stahls' is a simple-to-use clam heat press which is perfect for small productions. This machinery is lightweight and space-saving, therefore it is also suitable for portable heat printing opportunities. This apparatus has a digital time and temperature readout and a wide opening for easy layout. [94]

Figure 7.3.3.2 STAHLS thermal transfer press

7.3.4 Fusing machine

Fusing machine RPS-mini fusing press with Mayer metronic 250 digital controller is a continuous fusing press with an end-to-end feed.

Continuous fusing press machines usually have a motorised conveyor belt arrangement for the transportation of fusing components through all the processes. There are two common types of conveyor belts systems- end-to-end feed and return feed. With the end-to-end feed system, the garment details are transferred from the loading area, through the fusing and cooling section and finally delivered in the side located at the other end of the machine. [95]

Figure 7.3.4.1 Fusing machine RPS-mini fusing press

7.3.5 Lockstitch sewing machine

Juki DLN-415-4 is a high speed industrial mechanical universal sewing machine with a single needle feed. This machine enables to create stitch type 301. This machine is equipped with a thread winder and an automatic thread trimmer.

Figure 7.3.5.1 Juki DLN-415-4

7.4 Used software

7.4.1 Gerber AccuMark Pattern Design

The AccuMark Pattern Design Software by Gerber Technology is especially designed for the fashion industry to provide a good quality performance (Interface sample in Figure 7.4.1.1). This pattern design software is a reliable system for fashion designers and ensures precise measurements and patterns. It enables the users to operate easily the software due to its easy to learn and understand functionality which keeps the users from wasting time. [96]

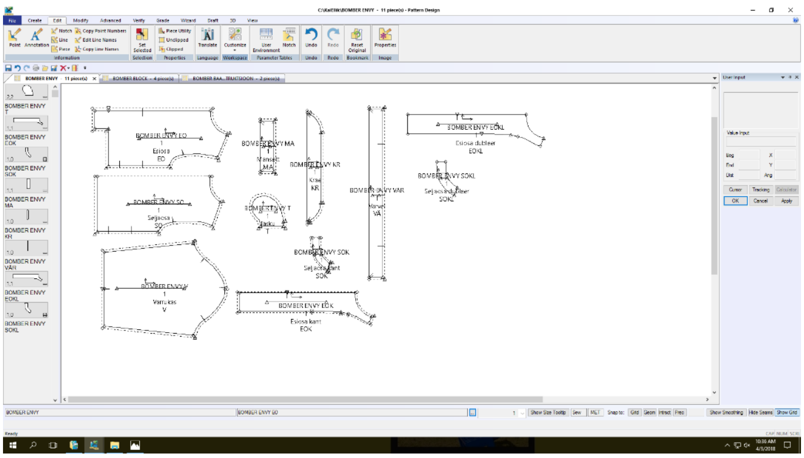


Figure 7.4.1.1 Gerber AccuMark Pattern Design interface

7.4.2 Kaledo Style

Kaledo Style is a software by Lectra is an illustration solution that can be used to create sketches (Interface sample in Figure 7.4.2.1). Kaledo Style software offers a variety of digital sketching and presentation features to enable users to create industry-ready presentations quickly and to a professional standard. Kaledo Style solutions can be used to create specification sheets, range boards, collection plans, and tech packs for manufacturing and production. [97]

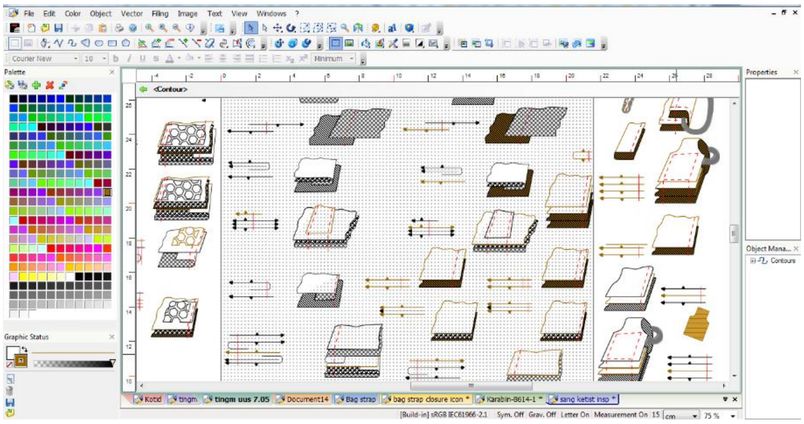


Figure 7.4.2.1 Kaledo Style interface

7.4.3 RDWorks v8

RDWorks is a free laser machine design and drawing software that enables users to perform laser cutting and engraving operations (Interface sample in Figure 7.4.3.1). This software has support for drawing points, horizontal and vertical lines polyline, ellipse/circle, rectangular/square, Bezier curve, text, and also for CAD models such as DXF, AI, and PLT. [98]

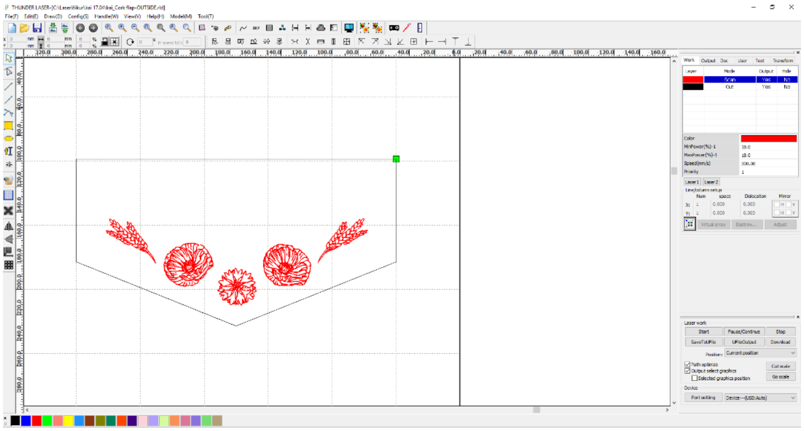


Figure 7.4.3.1 RDWorks v8 interface

7.4.4 Decostudio E3 Lite with Coreldraw by Wilcom

DecoStudio Lite E3 is Wilcom's entry-level embroidery software that is commonly packaged with new embroidery machines to help new users to get started with embroidery. This software is integrated with CorelDRAW Essentials X6 and therefore comes with a set of graphic design tools and vector to embroidery conversion. This programme offers easy-to-use lettering, monogramming, and basic editing tools, and is a cost-effective way to get started with custom embroidery. [99]

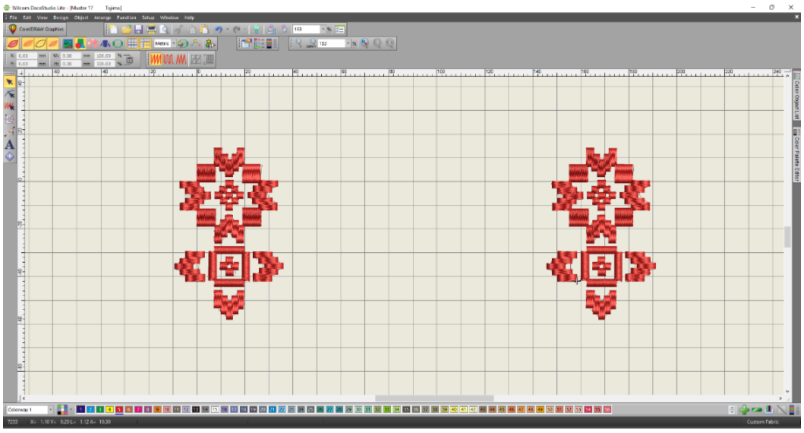


Figure 7.4.4.1 DecoStudio Lite E3 interface

8 MATERIAL TESTING RESULTS

8.1 Composition

8.1.1 FTIR

The adhesive part of the cork material was tested because there was nothing mentioned about the glue in the information obtained with the material purchase. Therefore, to test the adhesive layer of the material FTIR analysis method was used.

The biggest correlations that were found were 86.3% Elmer's White Glue and 85.06% Elmer's Carpenters Glue.

As it is visible from Figure 8.1.1.1 the different peaks that show absorption of both materials are mostly on the same wavelengths. Also, the peaks have similar heights. The correlation coefficient 86.03% of the best result is not very high, but the reason might be that the adhesive material has been already used for making this composite material and could, therefore, be contaminated. Also, some colorants have been added to the glue to make it more similar to the upper cork layer.

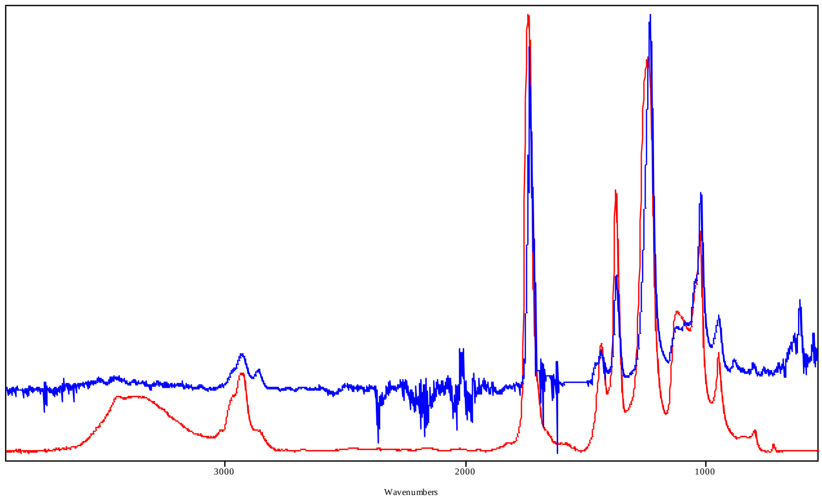


Figure 8.1.1.1 Spectral Library Search Results

The exact ingredients of Elmer's White Glue are not known as it is a business secret, but there is some information available regarding the origins of the ingredients. The first version of Elmer's white glue was introduced in 1947 as Cascorez Glue and contained casein from dairy milk. Currently, Elmer's does not use animals or animal parts to make glue and can, therefore, be considered vegan. But Elmer's adhesive products are made from synthetic petroleum-based ingredients, therefore, although they are vegan and no animals were harmed for making this product, the material overall isn't environmentally friendly and sustainable. [100]

8.1.2 Microscopy

In Figure 8.1.2.1 are visible the fibres taken from the warp direction. The fibres contained polyester fibres that have rod-like uniform appearance and cotton fibres that have a ribbon-like twisted appearance. Additional photos are in Appendix 2: A2.1, A2.2.

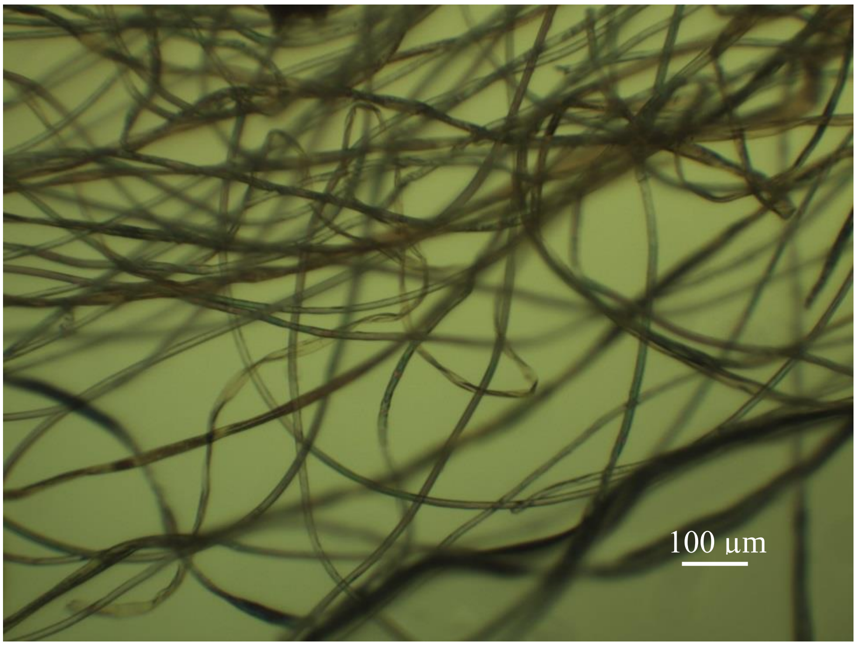


Figure 8.1.2.1 Fibres taken from warp yarn, 100x magnification

In Figure 8.1.2.2 are visible the fibres taken from the yarns taken from the weft direction. Additional photos are in Appendix 2: A2.3, A2.4. From the photos it can be observed that the fabric contained a lot of polyester fibres and only some cotton fibres.

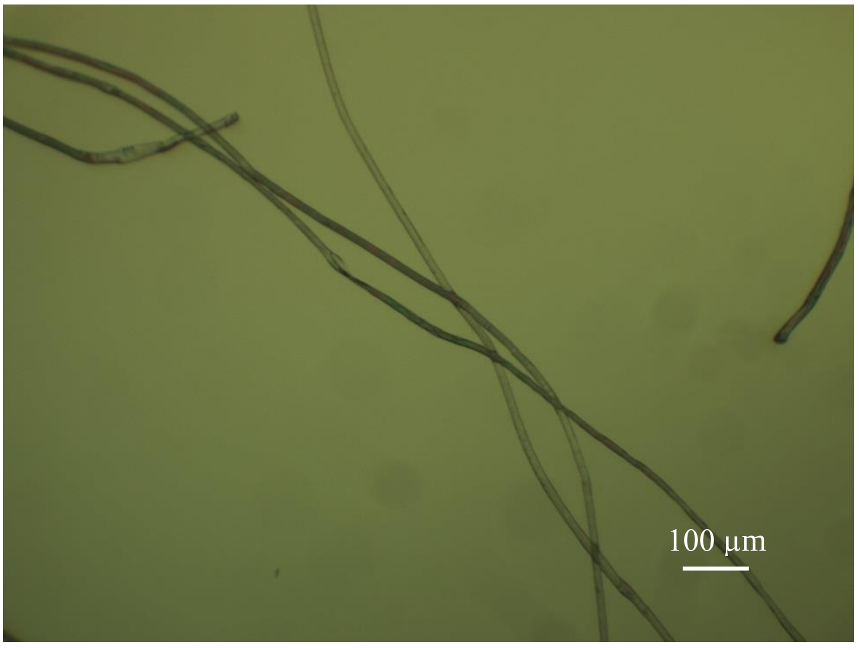


Figure 8.1.2.2 Cotton and polyester fibres taken from weft yarn, 100x magnification

8.1.3 Quantitative analysis of the composition

The calculations were done according to formulas 7.2.1.1 and 7.2.1.2.

Sample no 1:

The initial weight of the sample: 0,5166 g

Weight of the filter crucible: 16,0905 g

Final weight: 16,5228

$$m_{PE} = 16{,}5228 - \ 16{,}0905 = \ 0{,}4323 \text{ (g)}$$
$$m_{CO} = 0{,}5166 - \ 0{,}4323 = \ 0{,}0843 \text{ (g)}$$
$$w\%_{PE} = \frac{0{,}4323 \cdot 100\%}{0{,}4323 + 0{,}0843} = 83{,}68\%$$
$$w\%_{CO} = \frac{0{,}0843 \cdot 100\%}{0{,}4323 + 0{,}0843} = 16{,}32\%$$

Sample no 2:

The initial weight of the sample: 0,5064 g

Weight of the filter crucible: 16,2301 g

Final weight: 16,6556 g

$$m_{PE} = 16{,}6556 - \ 16{,}2301 = \ 0{,}4255 \text{ (g)}$$
$$m_{CO} = 0{,}5064 - \ 0{,}4255 = \ 0.0809 \text{ (g)}$$
$$w\%_{PE} = \frac{0{,}4255 \cdot 100\%}{0{,}4255 + 0{,}0809} = 84{,}02\%$$
$$w\%_{CO} = \frac{0{,}0809 \cdot 100\%}{0{,}4255 + 0{,}0809} = 15{,}98\%$$

The official information about the composition of the cork material that was used for this project stated that the outer layer is 100% cork and the inner layer is 63% cotton and 37% recyclable polyester. According to the results of this quantitative test the backing composition is only 16% cotton and 84% polyester.

8.2 Mass per unit area

The test results are given in Table 8.2.1 below and the calculations are in Appendix 3. Genuine leather had by far the biggest value for mass per unit area with the arithmetic mean of (737±21) g/m^2 and also the highest standard deviation. Piñatex® had the second highest value for the mass per unit area, with the arithmetic mean of (452±6) g/m^2. The mean result for cork material was (402±2) g/m^2 and for PU coated fabric (433±3) g/m^2. All the results for tested leather alternatives were rather similar.

Table 8.2.1 Mass per unit area test results and standard deviations

Material	**Standard**	**Mass**	**Standard deviation**
Cork material			
1.	EVS-EN 12127:2000	397.9 g/m^2	
2.		404.0 g/m^2	
3.		402.9 g/m^2	
4.		402.0 g/m^2	
5.		400.9 g/m^2	
Arithmetic mean		**401.5 g/m^2**	**2.3 g/m^2**
PU coated fabric			
1.	EVS-EN 12127:2000	431.1 g/m^2	
2.		436.4 g/m^2	
3.		429.2 g/m^2	
4.		435.8 g/m^2	
5.		434.7 g/m^2	
Arithmetic mean		**433.4 g/m^2**	**3.1 g/m^2**
Piñatex®			
1.	EVS-EN 29073-1:2000	459.6 g/m^2	
2.		448.3 g/m^2	
3.		448.7 g/m^2	
Arithmetic mean		**452.2 g/m^2**	**6.4 g/m^2**
Real leather			
1.	EVS-EN 2420:2017	749.52 g/m^2	
2.		749.50 g/m^2	
3.		713.26 g/m^2	
Arithmetic mean		**737.4 g/m^2**	**20.9 g/m^2**

8.3 Tear force

The test was conducted in an atmosphere of 25.4 ºC degrees and relative humidity of 50,0%. For this test, the standard specimen was used and the results were evaluated manually. The final test results are given in Table 8.3.1.

Table 8.3.1 Tear load test results

Material	Average length-wise, N	Average width-wise, N	Average, N
Cork material	43.4	21.9	32.6 ±12.1
Piñatex® Material	44.6	-	22.3 ± 4.3
PU coated fabric	27.4	8.9	18.2 ± 10.1
Vegetable-tanned leather	45.0	51.9	48.4 ± 5.6

The detailed results of the cork material are given in Appendix 8, and the obtained graphics are in Appendix 4. The results obtained with specimens cut so that the longer side is parallel to the weft direction had lower results and test specimens were not torn apart straight. Before the end, the material started to tear sideways, which might have been caused by the texture of the cork layer on the material. The mean result of six specimens was 32.6 N. The standard requirement for the leather upholstery furniture is > 20 N, so the obtained result would be satisfactory [54].

The detailed results of the Piñatex® material are given in Appendix 8, and the obtained graphics are in Appendix 5. The results obtained with specimens cut so that the longer side is parallel to the width direction had no results suitable for the evaluating method of the leather testing standard ISO 3377-1:2011. The test specimens were not torn apart straight, the material was torn apart horizontally, and the graphics had no well visible peaks. Other test specimens were torn apart straight and the mean result of the tear load was 44.6 N. As the standard requirement for the leather upholstery furniture is > 20 N, the obtained result with test specimens cut long side parallel to the length of the material would have a satisfactory result, but the test with specimens cut from other direction failed.

The detailed results of the PU coated fabric are given in Appendix 8, and the obtained graphics are in Appendix 6. The results obtained with the specimens cut so that the longer side is parallel to the weft direction had more than three times lower results but the test specimens were torn apart straight. The test specimens that were cut from the other direction had higher results but the test specimens were not thorned apart straight before the end the material started to tear slightly sideways. The material was elastic and stretched visibly during the test. The mean result of six specimens was 18.2 N. The standard requirement for the leather upholstery furniture is > 20 N, so the obtained result would not be suitable.

The results of the genuine vegetable-tanned leather are given in Appendix 8, and the obtained graphics are in Appendix 7. The results obtained were high for both types of test specimens but slightly higher for the pieces cut so that the longer side was parallel to the backbone. The mean result of six specimens was 48.4 N. The standard requirement for the leather upholstery furniture is > 20 N, so the obtained result would be well suitable. The overall results of the genuine leather specimens were higher that the results of the leather alternatives and the difference of the results obtained in both directions were the lowest.

8.4 Air permeability

Tested materials were Piñatex® Original black leather-like material, which is a non-woven material covered with PU coating, cork leather-like material, which is a composite material consisting of fabric backing, adhesive, and cork surface, PU coated leather-like material and a vegetable-tanned leather sample. The thicknesses of the tested materials are the following: Piñatex® Original black 1.45 mm, cork composite material 0.94 mm, leather 1.51 mm, and PU coated fabric 0,85 mm (Appendix 1).

The final test results are brought out on a Figure 8.4.1 below and the full test results are given in Appendix 9. The test results show that Piñatex® material has a much higher air permeability index value, than the cork-based leather alternative, leather, and faux leather, which was a fabric, covered with a PU coating. Therefore, Piñatex® material is much more permeable to air than those other tested materials. This is probably because the main part of this material is a non-woven material with a rather airy structure, and the PU coating is quite thin. The least permeable to air was PU coated leather-like material. This might be because the PU coating on this material is rather thick and the fabric beneath the coating has a dense structure. In general, the air permeability depends on the structure of the material, the structure of the yarns and threads, the density, the fibre composition. Also, the moisture content of the material and the temperature of the material and the environment affect the results.

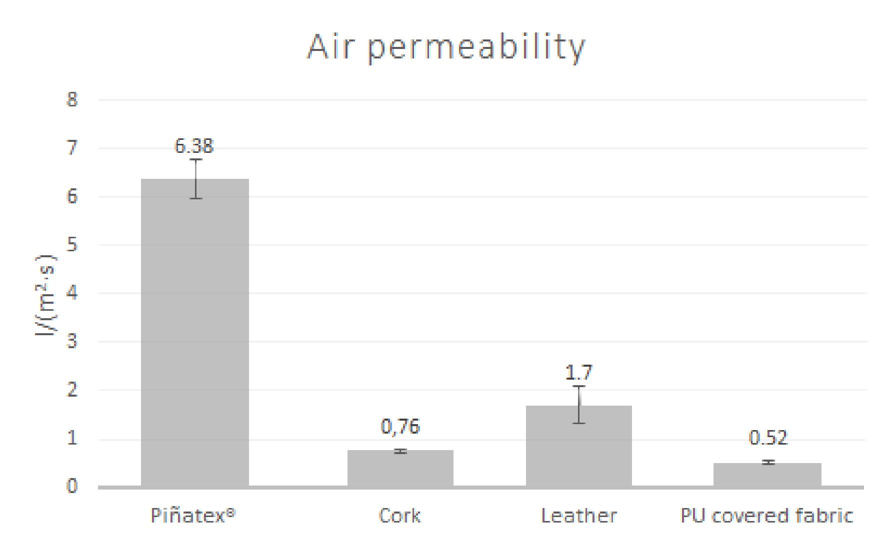


Figure 8.4.1 Results of air permeability test

8.5 Abrasion resistance

The final results of the abrasion resistance test are given in table 8.5.1 below, where is brought out test samples’ condition after the first cycle of 100 rubs and the number of rubs it took every sample to have more than four places of finishing breakdown.

Table 8.5.1 Martindale test results

	Piñatex® material		Cork material		PU covered fabric		Leather	
Sample no	1.	2.	1.	2.	1.	2.	1.	2.
After first cycle of 100 rubs								
Points of breakdowns	>4	>4	>4	>4	0	0	0	0
Appearance of material	Decent	Decent	Ruined	Ruined	Good	Good	Perfect	Perfect
Individual results								
>4 points of breakdowns, rubs	100	100	100	100	900	800	1600	1700
Average, rubs	100		100		850		1650	

Pictures of the test specimens taken with and without the optical microscope can be seen in Appendix 10. Figures A.10.1 - A.10.4 are about the first sample of Piñatex® material and figures A.8.5, A.8.6 about the second sample of Piñatex® material. Figures A.10.7 - A.10.10 are about the first sample of cork material and figures A.10.11 - A.10.14 about the second sample of cork material. Figures A.10.15 - A.10.18 are about the first sample of genuine leather and figures A.10.19 - A.10.21 about the second sample of leather. Figures A.10.22 - A.10.25 are about sample 1 of PU covered fabric and figures A.10.26, A.10.27 about the second sample of PU covered fabric.

8.6 Colour fastness to water spotting

The final results of the test are given in Table 9, and the only material that had a colour change on the material surface was vegetable-tanned leather. This material had no protective finishing and the water droplets left light but well-visible marks. There was no change with other test specimens.

Table 8.6.1 Results of the water spotting test

Material	**After 30 min**	**After 16 h**
Cork material	“5” – no change	“5” – no change
Piñatex®	“5” – no change	“5” – no change
PU covered fabric	“5” – no change	“5” – no change
Vegetable-tanned leather	“3/4” – moderate change	“3/4”- moderate change

8.7 Parameters for customizing methods

8.7.1 Laser cutting and engraving

Piñatex® and cork leather alternative samples were tested using different parameters on the laser cutting machine with a power of 100 W. The experimental part observed different specimens while changing properties and finding the optimal ones.

During testing the most optimal cutting power percentage seemed to be 21%, but during the production part it was found that due to slightly fluctuating thickness of the material the most suitable choice was 24%, as it gave clean results without leaving some threads uncut.

Piñatex® material is not suitable for engraving as the process only removes the coating part and reveals the fibres beneath. This does not give the aesthetically appealing look and the uncovered fibres are brittle and there are a lot of small fibre pieces falling from the engraved area.

Table 8.7.1 Laser cutting and engraving parameters

Material	**Process**	**Power**	**Speed, mm/s**
Piñatex®	Cutting	50%	550
	Engraving	-	-
Cork material	Cutting	24%	80
	Engraving	18%	300

8.7.2 Embroidery machine

Both Piñatex® and cork material were tested to use with Texi Iris 10 embroidery machine which is a small and compact, one-head, ten-needle industrial embroidery machine. Threads that were used were Madeira Polyneon 1838 red, 1800 black, 1904 green, and 1771 yellow. Neither of the materials needed additional backing while embroidering and suitable speeds were low 300 stitches per minute, but for Piñatex® 500 stitches per minute also didn't cause problems.

For the first test with Piñatex® the frame that was used was size 110x110 mm and no backing material was used. The used needle was number 75/11 and had FFG/SES point style. As a result, the material is suitable for embroidery and the test sample can be seen in Figure 8.7.2.1. The thread broke once during the process, but after reinstallation, it did not happen again. Thread tension seemed to be slightly too high, as the bobbin thread was slightly pulled to the surface of the material, but this can be adjusted during the next tests. The frame left strong marks on the material, that did not come out completely after pressing.

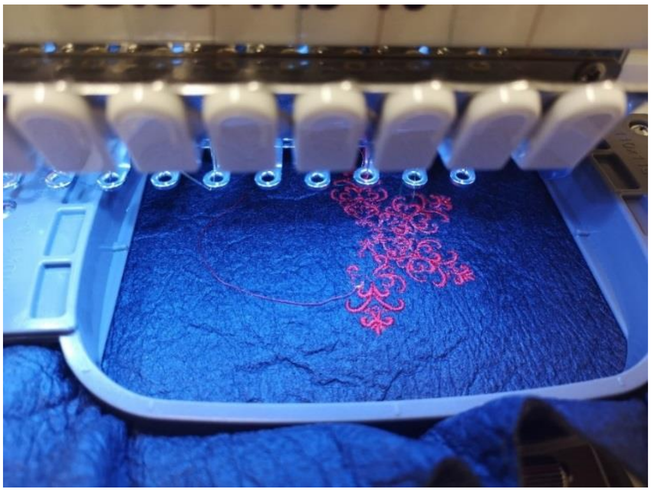


Figure 8.7.2.1 Embroidery on Piñatex®

Embroidery on cork material looked well refined and clean and the cork material surface surrounding the embroidery was not damaged in the process. The needle used for cork material was number 75/11 and had FFG/SES point style. As the cork material has a thick adhesive layer between the cork layer and the textile layer, the material changed its form due to the machine frame and tension caused by the threads, but the material regained its form later. An example can be seen in Figure 8.7.2.2.

Figure 8.7.2.2 Testing embroidery on cork material

Table 8.7.2.1 Embroidery machine settings

Material	Backing	Thread	Speed s.p.m.*
Piñatex®	No backing	Madeira Polyneon	500
Cork material	No backing	Madeira Polyneon	300

*s.p.m- stitches per minute

8.7.3 Textile printer

It was tested if cork material is a suitable material to use with a textile printer. The printed design was fixed using presser with 120º C for 2 minutes. The test was successful and the temperature chosen was suitable, as the material had no thermal damage and design was well-fixed. The only problem was that the lines were slightly fuzzy as the ink had a bleed on some places due to the material surface structure were some places are higher and others deeper and not covered with cork, therefore, revealing the glue layer. This problem might be removed or reduced by applying less ink while printing.

Figure 8.7.3.1 Print on a cork material

8.8 Analyse and comparison

All test results have been gathered into table 8.1.1 to give a clearer overview and bring out some important points.

Table 8.8.1 Test results comparison

Characteristic		Material				Standard requirement (ISO 13336:2012) (ISO 14931:2015)
		Piñatex® Original Charcoal	Cork material	PU covered fabric	Genuine vegetable-tanned leather	
Thickness, mm		1.45±0.06	0.93±0.02	0.85±0.02	1.51±0.09	-
Mass per unit area, g/m^2		452±6	402±2	433±3	737±21	-
Tear force, N	Length-wise	44.6±4.3	43.4±4.0	27.4±0.5	51.9±4.3	Average >20 N
	Width-wise	-	21.9±2.1	8.9±0.1	45.0±4.9	
Air permeability, l/(m^2·s)		6.38±0.39	0.76±0.03	0.52±0.33	1.70±0.03	-
Martindale, rubs		100	100	850	1650	-
Colourfastness to water spotting, evaluation in grey scale		"5"	"5"	"5"	"3/4"	≥3 grey scale
Production methods						
Cutting with laser cutting machine		Suitable	Suitable	Unsuitable	Suitable	
Engraving		Unsuitable	Suitable	Unsuitable	Suitable	
Embroidery machine		Suitable	Suitable	Unsuitable	Suitable	
Textile printer		Unsuitable	Suitable	Unsuitable	Suitable	

There are no standard requirements for leather used for handbags, so in this table are brought out standard requirements for leather upholstery (ISO 13336:2012) and leather apparel (ISO 14931:2015).

The greatest weakness of Piñatex® and cork material was the abrasion resistance, where the results were really low and the surfaces had more than 4 finishing breakdowns. This might mean that those materials are not very durable and long-lasting with heavy use.

Another disadvantage was that the Piñatex® material had really low results in the tear strength test width-wise direction. This means that the material can be thorn much easier in a perpendicular direction to the manufacturing direction. This can be a problem for smaller and thinner details.

Piñatex® material was much more permeable to air than the other tested materials. With clothing products this might refer that the material is more breathable which can have a great effect on material comfortability.

Piñatex® and cork material showed very good results in colour fastness to water spotting test, where there were no changes in colour. This is a good result that might mean that those materials are easy to maintain and do not need special products to make the products more stain-resistant.

Piñatex® and cork material both had their advantages and disadvantages compared to real leather, but in general they seem to be less durable and therefore not a good choice for products with heavy use. Those materials might be suitable alternatives for leather products with more decorative purposes and accessories.

9 PRODUCT DESIGN AND DEVELOPMENT

9.1 Product design

All sample products (Figure 9.1.1, 9.1.2 and 9.1.3) are envelope types of bags that have the same base pattern but are customized differently using a laser cutting machine to create cut-out honeycomb structure and engravings to cork leather material and embroidery machine with Piñatex® pineapple leather material. Designs are inspired by Estonian folklore and traditional knitting patterns.

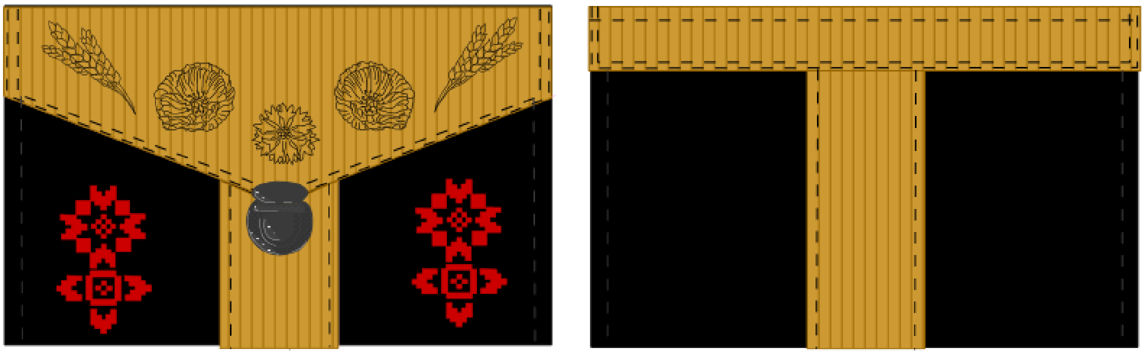


Figure 9.1.1 Design "Summerfield"

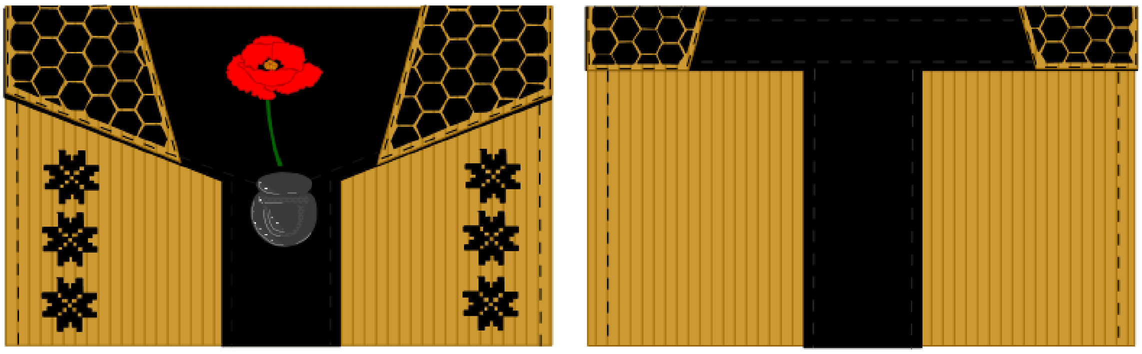


Figure 9.1.2 Design "Poppy"

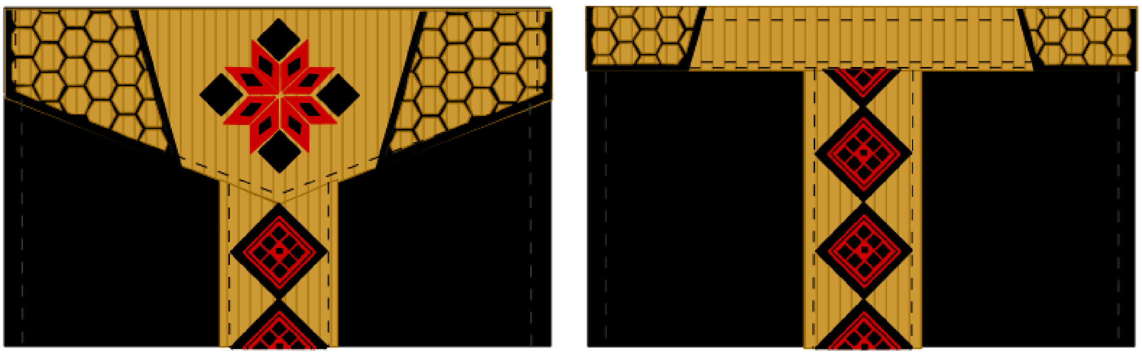


Figure 9.1.3 Design "Ethno"

Design “Summerfield” has a big engraving design on a flap that is inspired by Muhu embroidery patterns. The embroidery on the main detail is inspired by the knitting pattern “Paistu tõllakiri” (Figure 9.1.4).

Figure 9.1.4 Mittens with Paistu tõllakiri [101]

Design “Poppy” has a single poppy flower embroidery design on a flap that is inspired by Muhu embroidery flowers (Figure 9.1.5). Symmetric engravings on the main detail are known as “kaheksakand” pattern that is very common on traditional knitting designs and is also part of “Paistu tõllakiri”. The flap has also decorative cut-out honeycomb design as a reference to Estonian well-loved choral song “Ta lendab mesipuu poole”

Figure 9.1.5 Examples of Muhu embroidery designs in Craft shop Oad ja Eed of the Muhu Craft Association [102]

Design “Ethno” has on a flap an embroidery design with a bigger variation of “kaheksakand” pattern (Figure 9.1.6). On the centre detail is a simplified pattern inspired by knitted belt design from Valjala (Figure 9.1.7). This bag has also cut-out honeycomb design similar to the bag “Poppy”.

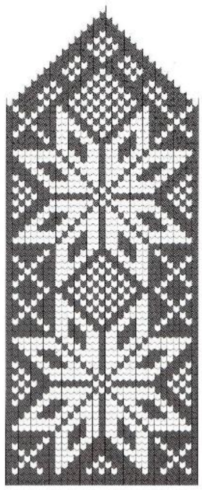


Figure 9.1.6 Variation of "Kaheksakand" pattern [103]

Figure 9.1.7 Belt pattern from Valjala [104]

Bag strap designs repeat the honeycomb pattern that is also found on bag designs. One of the bag straps is made of cork material and has a honeycomb pattern engraved surface of the outer layer (Figure 9.1.8). Another bag strap is made of two layers of Piñatex® material, of which the outer layer has cut-out honeycomb design which reveals the inner cork layer (Figure 9.1.9).

The third bag strap is narrower, shorter and more elegant looking and is made by combining a metal chain with a strip of cork material (Figure 9.1.10).

Figure 9.1.8 Bag strap made from cork material

Figure 9.1.9 Bag strap made mainly from Piñatex®

Figure 9.1.10 Bag strap made of metal chain and cork material

9.1.1 Pattern making

The bag patterns were made with the Gerber AccuMark Pattern Design software. The initial patterns for the envelope bags were made according to the first design sketches of the bag designs. Bags have a lining, and the overall measurements of the bags are 25 x 15 cm. The initial proportions of the designs were slightly reconsidered, making the bag less square.

Later, the patterns were slightly changed: some seam allowances were added or changed, and the lining part was divided into two parts- the main detail and flap (Figure 9.1.1.1). Base patterns for bag straps are shown in Figure 9.1.1.2. The tables of each bags' pattern lists are given in Appendix 11.

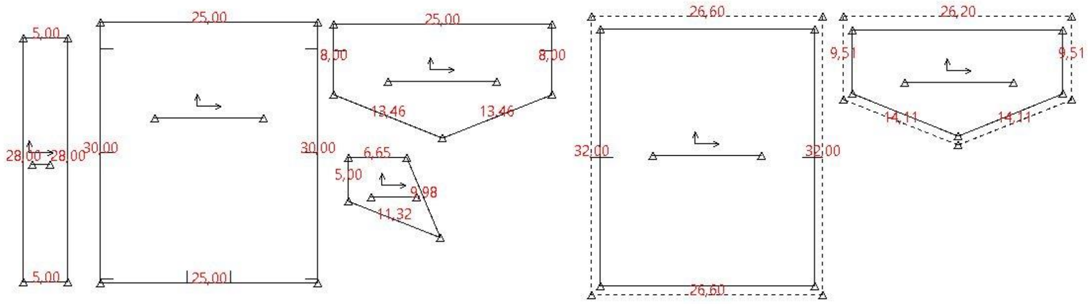


Figure 9.1.1.1 Final bag patterns

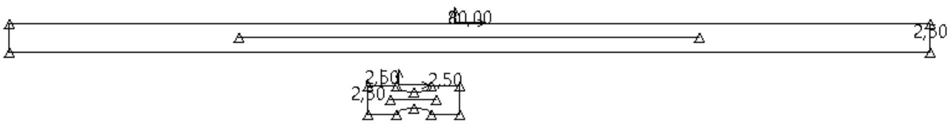


Figure 9.1.1.2 Bag strap patterns

9.1.2 Laser cutter files

Laser cutter files were created using special laser engraving and cutting software RDWorks v8. This software is a freeware programme that supports a variety of different vector formats and bitmap formats but as the vector images give the clearer final result the preferred format used is DXF. It is possible to adjust the speed, s, and power, W. Sample bag details that are made of cork material need to be cut out using laser cutting machine so that the edges would not unravel.

The flap detail engraving had to be tested to ensure that the placement is correct (Figure 9.1.2.1). The first test was made using denim material so that the expensive material used for the bags would not be wasted (Figure 9.1.2.2). The engraving design on the flap was slightly changed after the first test as the cornflower blossom on the middle was slightly too low and would have been too close to the tuck lock buckle, and wheat heads were slightly too high and close to the bending line of the flap. Design elements were brought slightly closer together without reducing the sizes.

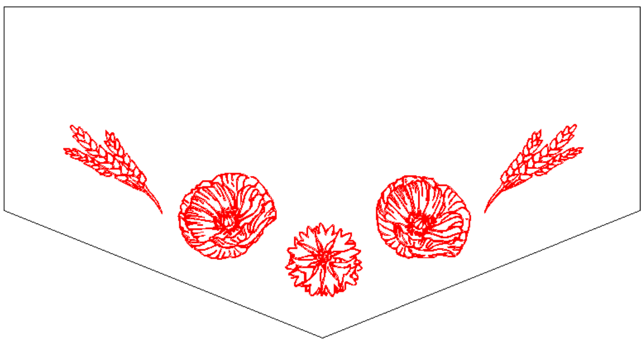


Figure 9.1.2.1 Flap detail with engraving design

Figure 9.1.2.2 Test for engraving design placement

The main detail (Figure 9.1.2.3) has two symmetrical rows of patterns on both sides of the bag, so it is important to make sure that the engravings are symmetric and would not be covered by the flap.

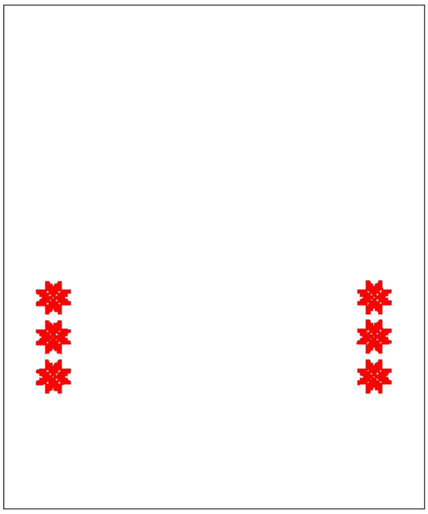


Figure 9.1.2.3 Main detail with engraving design

Two of the sample bags have two symmetric additional decorative details that have cut-out honeycomb patterns on them (Figure 9.1.2.4).

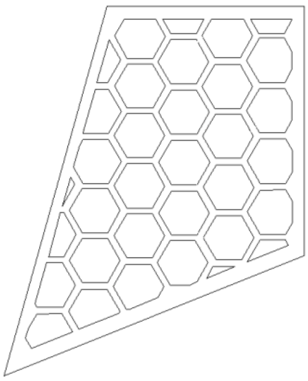


Figure 9.1.2.4 Flap decorative detail cut-out design

9.1.3 Embroidery files

The embroidery files were created using Decostudio E3 Lite with Coreldraw by Wilcom. Files need to be in DST format to get a satisfactory result with Texi Iris 10 embroidery machine.

There are three embroidery designs created for final sample bags. One of them is a poppy design (Figure 9.1.3.1) that originally used four different coloured threads, but as there were problems with the last section of the design, where the black colour was filled in. This part was removed, as the threads tangled due to the small and dense stitches, and also, it seemed to be unnecessary as the background colour of the bag is already black. The second design is a symmetric pattern (Figure 9.1.3.2) that is going to be placed on the main detail of the bag. The third one is a design inspired by the Estonian knitting pattern and has two different coloured threads- red and black (Figure 9.1.3.3).

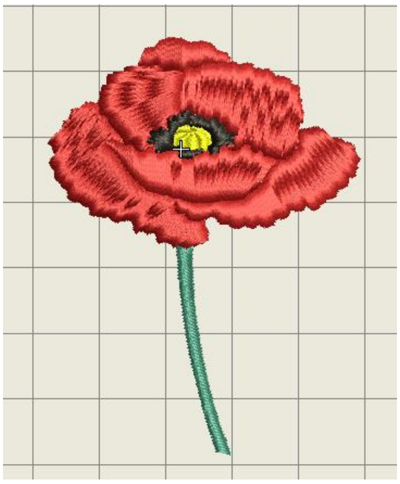


Figure 9.1.3.1 Poppy embroidery design for a flap

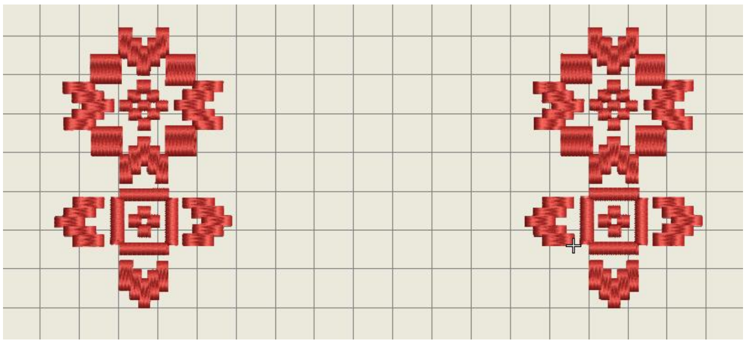


Figure 9.1.3.2 Pattern embroidery design for the main detail

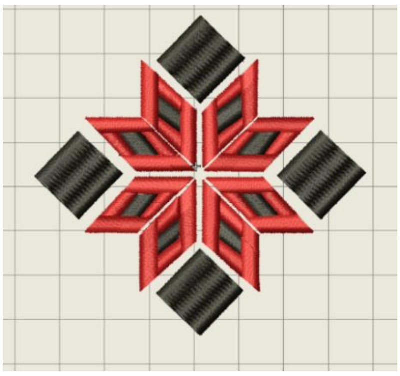


Figure 9.1.3.3 Embroidery design for a flap detail

While testing the created files it was acknowledged that the thread tension of bobbin thread was too high and therefore the white bobbin thread was pulled into the surface of the material. The tension was adjusted by turning the screw of the bobbin case. After the adjustment, the result was clearer and there were no white threads visible from the edges of the design.

Figure 9.1.3.4 Testing embroidery files on Piñatex®

9.2 Production technology

9.2.1 First prototype

The first basic prototype was made to decide on suitable processing technologies of the bag. The main aspects that needed to be tested were the suitable sewing sequence, method for attaching the lining with the main materials, suitable closure type.

There were different methods tested for attaching the lining. The first method was to use textile glue to fix the lining to the correct position and later it is going to be securely held in the correct place with the sewing of the bag sides. The second method was to use adhesive fabric between the lining and main detail and fix them together using a hot iron, and the third method was similar but two parts were pressed together using a fusing machine. The textile glue that was used to test out the first method was Casco textile glue (Textillim), the glue had to be spread evenly as a thin layer on both materials that were going to be glued together, then 30 minutes had to wait before the parts could be pressed together. Then it had to be waited for another 10- 20 minutes. This process was not only time-consuming but also completely unsuitable for the materials chosen for this product, as the glue was difficult to spread on the non-smooth back part of the Piñatex® material and the glue bleed through the lining material. Also, the glue took much more time to dry completely, as it was still feeling moist the next day after more than 24 hours had passed. The second and third methods both worked well, as the lining was well-attached, and materials were not ruined during the processes. The ironing gave a less smooth final look than the fusing machine, as the machine was capable of giving strong even pressure on the attached details. For Piñatex® material suitable fusing machine parameters were 133º C and 3,0 s and for cork material 130º C and 3.5 s.

Different bag closure types that were tried out were magnet closures and a tuck lock buckle. Both tested closure types worked well-enough and were easy to attach to the Piñatex® and cork material. The craft knife was used to make suitable holes in the material to ease pressing the legs of the closure accessories through materials. Both closure types were tested in the simplest method by opening and closing them 100 times in a row and they passed it with no complications. The buckle closure was chosen as the final result looked better and also it made the over-all processing technology of the bag slightly easier.

The detailed production technology of the prototype bag is in Appendix 12.

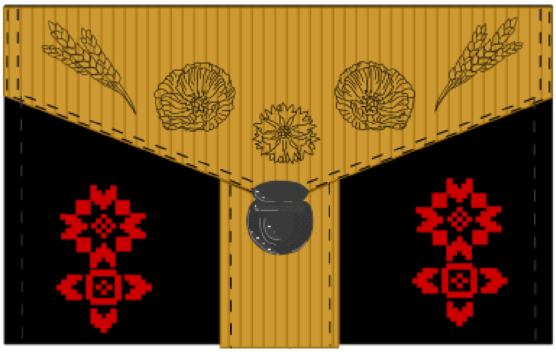
Figure 9.2.1.1 First sample product prototype with tuck lock buckle closure

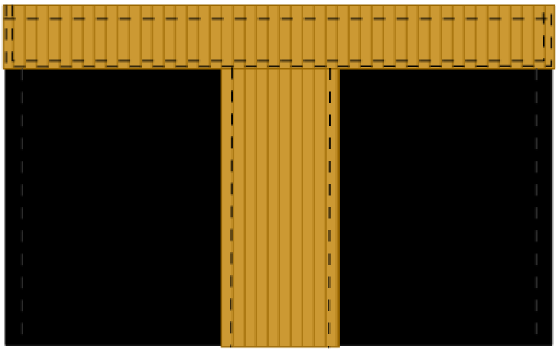
Tables with the production technology processes of the final bags are brought out in Appendix 13 (bag "Summerfield"), Appendix 14 (bag "Poppy"), and Appendix 15 (bag "Ethno"). Tables with the production technologies of the bag straps are given in Appendix 16 (Bag strap "Style 1"), Appendix 17 (Bag strap "Style 2"), and Appendix 18 (Bag strap "Style 3"). And explanation of the symbols is given in Appendix 19.

9.2.2 Specification sheets

Specification sheet: Bag "Summerfield"

Model name	**Model no**	**Product type**	**Season**	**Process engineer**
Summerfield	001	Envelope bag	All year	Kai Ellik
Main detail material	**Flap and centre detail material**	**Lining material**	**Adhesive fabric**	
Piñatex® Original Charcoal	Rustic Natural Cork Fabric COF-240	Black, art. 2380	Grey, art. 4223	





Main detail material composition: 72% PALF, 18% PLA, 10% PU
Flap and centre detail composition: Outer layer: 100% cork;
Inner layer: 16% CO, 84% PL
Lining material: 100% PL
Adhesive material: 100% PA

Adhesive material was used between the layer of the main detail and the lining detail of the main detail
In the centre of the bags' front side is a metallic tuck lock buckle

In the flap detail is an engraving design
In the main detail are symmetric red coloured patterns

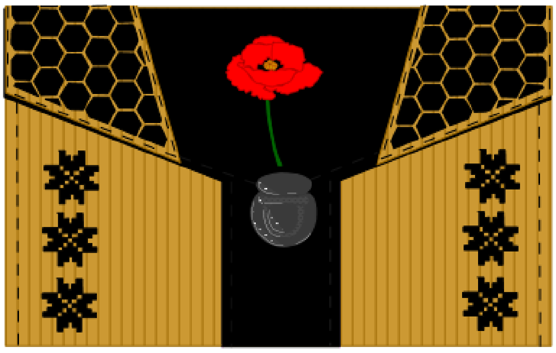
Maintenance:

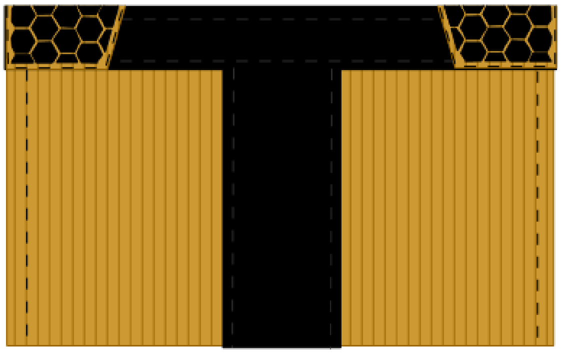
Machinery: Universal sewing machine, Fusing machine
Needle: no 90, R
Thread: no 50 (joining of the main detail and lining) and silk thread (all other seams)
Stitch type: 301

- Main detail and lining detail shorter edge joining: seam width 0.5 cm
- Main detail and lining joining with adhesive textile using fusing machine: Temperature 130 ºC, time 3.0 s
- Centre detail joining with the main detail: seam width 0.5 cm
- Flap outer and inner details joining: seam allowance 0.5 cm
- Flap detail top-stitching: seam allowance 0.2 cm
- Flap and main detail joining: seam allowance 0.5 cm and 2.5 cm
- Bag sides joining: seam allowance 0.5 cm

Specification sheet: Bag "Poppy"

Model name	**Model no**	**Product type**	**Season**	**Process engineer**
Poppy	002	Envelope bag	All year	Kai Ellik
Main detail and flap decorative detail material	**Flap and centre detail material**	**Lining material**	**Adhesive fabric**	**Fusible material**
Rustic Natural Cork Fabric COF-240	Piñatex® Original Charcoal	Black, art. 2380	Grey, art. 4223	Black, art. 3100





Main detail and decorative flap detail material composition:
Outer layer: 100% cork;
Inner layer: 16% CO, 84% PL
Flap and centre detail composition: 72% PALF, 18% PLA, 10% PU
Lining material: 100% PL
Adhesive material: 100% PA
Fusible material: 100% PL

Adhesive material was used between the layer of the main detail and the lining detail of the main detail
Fusible material was used on the reverse side of the cork material
In the centre of the bags' front side is a metallic tuck lock buckle

In the flap detail is an embroidery design
In the main detail are symmetric engraving designs

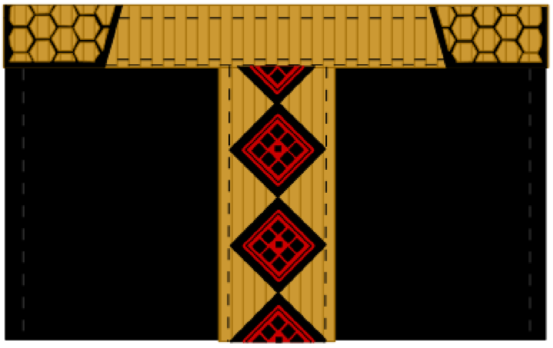
Maintenance:

Machinery: Universal sewing machine, Fusing machine
Needle: no 90, R
Thread: no 50 (joining of the main detail and lining) and silk thread (all other seams)
Stitch type: 301

- Main detail strengthening with fusing material using fusing machine: Temperature 130 ºC, time 3.0 s
- Main detail and lining detail shorter edge joining: seam width 0.5 cm
- Main detail and lining joining with adhesive textile using fusing machine: Temperature 130 ºC, time 3.0 s
- Centre detail joining with the main detail: seam width 0.5 cm
- Flap detail and lining joining: seam allowance 0.5 cm
- Flap decorative detail joining: seam allowance 0.2 cm
- Flap and main detail joining: seam allowance 0.5 cm and 2.5 cm
- Bag sides joining: seam allowance 0.5 cm

Specification sheet: Bag "Ethno"

Model name	**Model no**	**Product type**	**Season**	**Process engineer**
Ethno	003	Envelope bag	All year	Kai Ellik
Main detail and flap decorative detail material	**Flap and centre detail material**	**Lining material**	**Adhesive fabric**	
Piñatex® Original Charcoal	Rustic Natural Cork Fabric COF-240	Black, art. 2380	Grey, art. 4223	



Main detail and decorative flap detail material composition:
72% PALF, 18% PLA, 10% PU
Flap and centre detail composition:
Outer layer: 100% cork;
Inner layer: 16% CO, 84% PL
Lining material: 100% PL
Adhesive material: 100% PA

Adhesive material was used between the layer of the main detail and the lining detail of the main detail
In the centre of the bags' front side is a metallic tuck lock buckle

In the flap detail is an embroidery design
In the centre detail is a printed design

Maintenance:

Machinery: Universal sewing machine, Fusing machine
Needle: no 90, R
Thread: no 50 (joining of the main detail and lining) and silk thread (all other seams)
Stitch type: 301

- Main detail and lining detail shorter edge joining: seam width 0.5 cm
- Main detail and lining joining with adhesive textile using fusing machine: Temperature 130 ºC, time 3.0 s
- Centre detail joining with the main detail: seam width 0.5 cm
- Flap outer and inner details joining with adhesive textile using fusing machine: Temperature 130 ºC, time 3.5 s
- Flap top-stitching: seam allowance 0.2 cm
- Flap decorative detail joining: seam allowance 0.2 cm
- Flap and main detail joining: seam allowance 0.5 cm and 2.5 cm
- Bag sides joining: seam allowance 0.5 cm

9.3 Product maintenance

It is recommended for Piñatex® Original/Pluma materials to be waxed with colourless wax to keep them looking hydrated. Wax should be applied with a clean cloth and then left to dry in a warm place. It is also recommended to use a product such as Liquidproof Protector™, a natural non-toxic coating that will make the product more stain and water repellent. Piñatex® material is heat resistant but it cannot subject to temperatures above 120°C for long periods of time. [20]

Cork material is claimed to be stain-resistant and waterproof, therefore not needing a lot of maintenance. Cork materials are usually recommended to be cleaned using soap and water, but some sources recommend using a mild dish-washing detergent or a mild liquid detergent to clean the surface. The soft wet and soapy cloth can be used to gently clean the cork surface and when the stains are removed another soft cloth should be used to dry the material. [105] It has been tested that the material could not only be cleaned by using wet cloth but can also be soaked in the water without ruining the material that could be left to air dry. [106]

9.4 Sample products analyse

All the designs were finished and the final results resembled very well the final design sketches. After making the prototype, there were some improvements and optimizations made in the initial processing technology and all the final bags have different technologies from each other.

Figure 9.4.1 Finished bags: "Summerfield" with bag strap Style 2, "Poppy" with bag strap Style 3, and "Ethno" with bag strap Style

All engravings on cork material looked good and had a natural-looking slightly faded look. The embroidery designs on both Piñatex® and cork material looked precise and professional. The printed design on the bag "Ethno" did not look as good as anticipated as the design was deformed by the uncovered adhesive areas on the surface.

Cork material could not be used as a single layer, as it was too thin compared to Piñatex® material, therefore bags "Summerfield" (Left one in Figure 9.4.1) and "Ethno" (Right one in Figure 9.4.1) had flaps made with two layers of cork material to give the flap better form. As the bag "Summerfield" had two layers joined each other just by sewing, the final flap was not as smooth and snug as the result for the bag "Ethno" were the two layers were joined using double-sided adhesive fabric in between.

The cut-out honeycomb structures were used for designs "Poppy" (Middle one in Figure 9.4.1) and "Ethno". The design worked well with cork material, as the result felt stable and durable, but the same design with Piñatex® material resulted in easily damageable details that were strongly affected by the sewing process and the bending of the flap. As Piñatex® material is mainly non-woven material where fibres are pressed together, small and thin details do not have enough durability, and stretch very easily pulling fibres apart. This problem might be solved, and the same design used with Piñatex® material if the material is previously strengthened with fusible material and then cut with the laser cutting machine.

10 DISCUSSION

There were six different types of tests conducted with Piñatex® and cork material, and as a result, Piñatex® and cork material both had their strengths and weaknesses compared to real leather, but in general, by the results, they appeared to be less durable and therefore not a good choice for products that have to withstand heavy use. Piñatex® and cork material showed potential as suitable alternatives for leather products with mainly decorative and light-use purposes.

During the tests for different material customization and processing methods laser cutting machine, embroidery machine, and textile printer were used. Fusing machine and industrial universal sewing machine worked well for material joining, and no additional more advanced machinery was needed. Materials processing methods' effectiveness and material prices are brought out as a comparison in table 10.1 below.

Piñatex® material can be cut with a laser cutting machine, embroidered without using any backing material, and the material is good to sew with. Cork material can be cut and engraved well with the laser cutting machine and embroidered without backing materials. Cork material can be cut and engraved well with the laser cutting machine and embroidered without backing materials. Cork material can also be used with a textile printer, although the ink will bleed slightly giving the original design a less clean and polished look. The problem with tested cork material was that it had many areas on the surface were the cork layer did not cover the adhesive layer and those spots deformed the design strongly. Cork is also good to sew with, although it was slightly challenging with smaller seam allowances. PU covered fabric is not suitable for a laser cutting machine and textile printer. The sample material that was tested for this thesis was rather thin and stretchy and therefore also not suitable for the embroidery machine. PU covered fabric is also less stable to sew than Piñatex® material, cork material, and genuine leather. Genuine leather is suitable for cutting and engraving with the laser cutting machine, embroidering if the material is thin enough for the frames of embroidery machines and can be printed on with textile printer. Genuine leather is also quite good to sew with.

Genuine leather was the most expensive among the tested materials, and Piñatex® material was the second most expensive but still about half the price of the real leather. This is a strong advantage for leather alternatives.

Genuine leather needs more maintenance than tested leather alternatives, as real leather needs specific products, but Piñatex® material, cork material, and PU covered fabric can usually be cleaned just by using a wet cloth and if needed also a mild soap.

Table 10.1 Materials processing comparison

	Piñatex®	**Cork material**	**PU covered fabric**	**Genuine leather**
Price per dm²	0.32 EUR	0.25 EUR	0.09 EUR	0.66 EUR
Laser cutting	+	+	-	+
Engraving	-	+	-	+
Embroidery	+	+	-	+
Printing	-	+-	-	+
Sewing ease	+	+-	+-	+
Maintenance	+	+	+	-

Final sample products (Figure 10.1) were in general satisfactory. Piñatex® material and cork material are suitable leather alternatives for handbags and other accessories that would not get too heavy use and abrasion. Nevertheless, as with all kinds of materials, there are some shortcomings as well as strengths that have to be considered while designing and developing a product.

Figure 10.1 Finished sample bags

SUMMARY

The main aim of the thesis was to test the processability of two commercially available plant-based leather alternatives by making sample products, envelope bag collection out of Piñatex® material (made with pineapple leaves), and cork leather-like material, and analyse the results. The bag collection consists of three envelope bags and three bag straps, that can be mix-matched with each other.

Genuine leather is a material with a long history and a lot of different end-uses throughout the time. Currently, it is still a very popular choice for shoes, bags, and other accessories, also for upholstery and vehicle interior solutions. As animal rights and environmental impact awareness are shifting peoples' preferences towards cruelty-free sustainable materials, there is already a variety of different types of leather alternatives based on natural and renewable raw materials.

In the theory part of this thesis, a selection of different plant-, fungi- and bacterial-based leather alternatives were explored to get a wider understanding of different possibilities in that field. A lot of those materials are still in active development and not ready to be commercially available.

In the first half of the practical part of this thesis, two of the most well-known and commercially available leather alternative materials Piñatex® material and cork-covered textile were tested parallel to samples of PU covered fabric and real leather for their tear strength, air permeability, abrasion resistance, colourfastness to water spotting. Piñatex® material and cork-covered textile were less durable in terms of abrasion but had better colour fastness to water spotting. Piñatex® material had very low tear strength in perpendicular to production direction, but very good results for other direction. Piñatex® was also much more permeable to air than other tested materials, due to consisting mainly of non-woven material.

In the second half of the practical part of this thesis, Piñatex® material and cork-covered textile were combined to create sample products. The sample products were designed to have a slightly romantic look with Estonian folklore- inspired designs. All bags have the same base pattern but different designs due to different customization techniques - laser cutting machine for cut-out structures and engravings, embroidery machine for embroidery designs, and textile printer for printed designs. Detailed production technology descriptions and product specification sheets were also created. Developed bags with current production technology are not suitable for mass production and are more novel products for a niche market.

Finished sample bags and bag straps were in general satisfactory and Piñatex® material and cork material are suitable leather alternatives for handbags and other accessories that would serve a mainly decorative purpose and would not get not heavy use. Both materials had some shortcomings as well as strengths that have to be taken into account while designing and developing a product. It should also be taken into account that there are different types of cork covered textiles on the market, that have slightly different properties and Piñatex® material is a rather new material that is still in the process of active improvement.

KOKKUVÕTE

Käesoleva magistritöö põhieesmärgiks oli testida alternatiivsete materjalide sobivust naturaalse naha asendamiseks. Alternatiivseteks materjalideks valiti kaks vabalt müügil olevat taimsel toormel põhinevat tekstiilmaterjali - Piñatex® materjal (ananassilehtedest materjal) ja korgiga kaetud kangas. Neid kahte alternatiivset materjali kasutades valmistati näidistooted, ümbrikkottide kollektsioon, ja analüüsiti saadud tulemusi.

Looduslik nahk on pika ajalooga materjal, millel on olnud väga palju erinevaid kasutusviise. Tänapäeval on naturaalne nahk endiselt väga populaarne valik jalanõude, kottide, pehmemööbli ja aksessuaaride valmistamisel. Sellele vaatamata on loomade õiguste ja keskkonna mõjude teavitustegevus hakanud inimeste eelistusi „julmuse vabade" (ühtki looma ei ole kahjustatud) ning jätkusuutlikumate materjalide poole suunama. Olemas on juba palju erinevaid alternatiivseid materjale nahale, mis baseeruvad looduslikul ja taastuval toormel.

Antud magistritöö teoreetilises osas uuriti erinevaid seentel, taimsel ja bakteriaalsel toorainel põhinevaid alternatiivseid materjale. Paljud neist materjalidest on siiani aktiivses arendusjärgus ning ei ole veel laialdaselt kättesaadavad. Samuti uuriti looduslikku nahka, sellest valmistatavaid tooteid ja toodete valmistamisel kasutatavaid meetodeid.

Magistritöö praktilise osa esimeses pooles valiti kaks tuntuimat ja vabalt müügil olevat naha alternatiivmaterjali - Piñatex® materjal ja korgiga kaetud kangas, et testida nende omadusi võrdluses polüuretaaniga kaetud kanga ja taimpargitud nahaga. Antud materjalide puhul testiti tõmbetugevust, hõõrdekindlust, õhuläbilaskvust, värvipüsivust veepiiskadele. Piñatex® materjal ja korgiga kaetud kangas olid nahast vähem vastupidavad hõõrdumise toimele, kuid omasid nahast paremat värvipüsivust veepiiskade toimele. Piñatex® materjalil oli väga madal tulemus tõmbetugevuse katses katsekehade puhul, mis olid lõigatud risti tootmissuunaga, kuid nahaga samaväärsed tulemused tootmissuunas välja lõigatud katsekehade puhul. Piñatex® materjalil oli testitud materjalidest kõige kõrgem õhuläbilaskvustegur, mis tuleneb antud materjali lausmaterjalil põhinevast struktuurist.

Antud magistritöö praktilise osa teises pooles valmistati näidistooted, kombineerides Piñatex® materjali ja korgiga kaetud kangast. Toodetel on kergelt romantiline stiil ja Eesti folklooril põhinevad disainid. Kõikidel kottidel on sama baaskonstruktsioon, aga samas on kasutatud erinevaid töötlemise meetodeid nagu laserlõikuriga loodud väljalõigatud struktuurid ja graveeringud, tikkimismasinaga loodud tikandid ja tekstiiliprinteriga loodud disainid. Kottidele loodi ka põhjalikud tootmisprotsessi kirjeldused ja tootekaardid. Valminud kotid antud tehnoloogiaga ei ole sobilikud masstootmiseks ning on pigem uudsed tooted niši turule.

Üldjoones, võib järeldada, et Piñatex® materjal ja korgiga kaetud kangas on sobivad alternatiivsed materjalid looduslikule nahale kottide ja aksessuaaride valmistamisel, kuid neist valmistatavad tooted ei ole mõeldud igapäevaseks aktiivseks kasutamiseks. Mõlemal materjalil olid oma eripärad, millega tuleks tootmise puhul arvestada. Arvesse tuleks võtta ka, et korgiga kaetud nahalaadsete materjalide valik kaubanduses on lai ja seega nende omadused võivad erineda ning Piñatex® materjal on siiani pigem uus materjal, mille koostise ja valmistamise meetodite puhul tehakse siiani aktiivset arendustööd.

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APPENDICES

Appendix 1 Thickness of different materials

Table A1.1 Material thicknesses

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Piñatex®, mm	1.349	1.419	1.593	1.436	1.474	1.442	1.411	1.439	1.477	1.434
Average										**1.447 mm**
Standard deviation										0.059
Cork, mm	0.934	0.936	0.922	0.924	0.890	0.912	0.963	0.917	0.909	0.950
Average										**0.926 mm**
Standard deviation										0.020
PU leather, mm	0.833	0.860	0.830	0.853	0.869	0.834	0.850	0.834	0.878	0.886
Average										**0.853 mm**
Standard deviation										0.019
Genuine leather, mm	1.492	1.566	1.425	1.647	1.549	1.615	1.481	1.535	1.444	1.364
Average										**1.512 mm**
Stangard deviation										0.088

Appendix 2 Microscopy images of cork material base

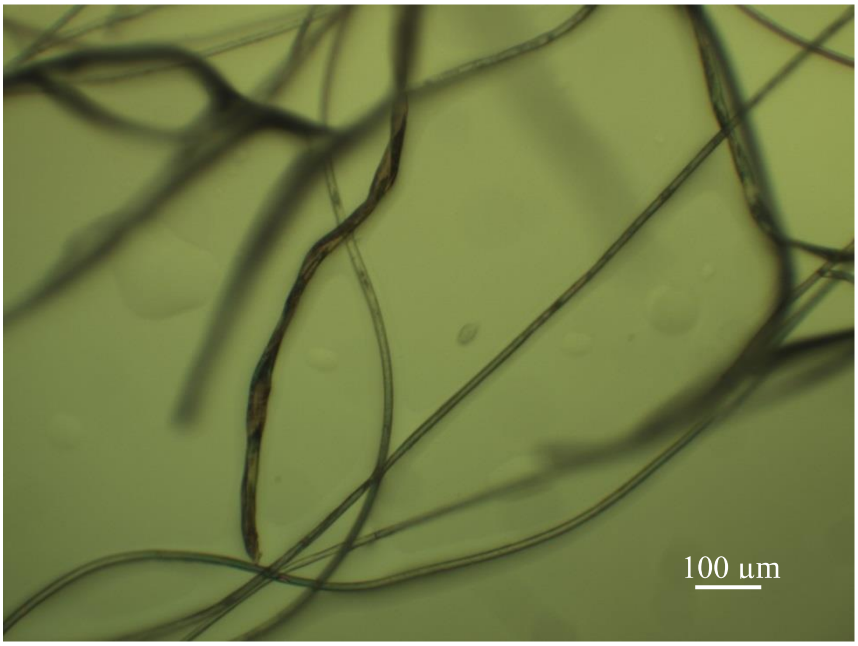


Figure A2.1 Cotton and polyester fibres taken from warp yarn, 100x magnification

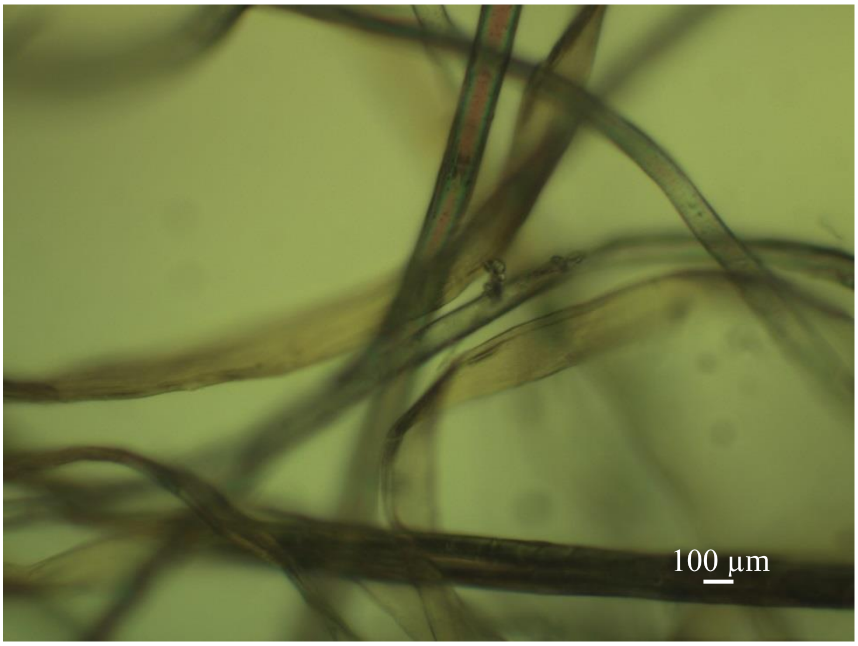


Figure A2.2 Fibres taken from warp yarn, 400x magnification

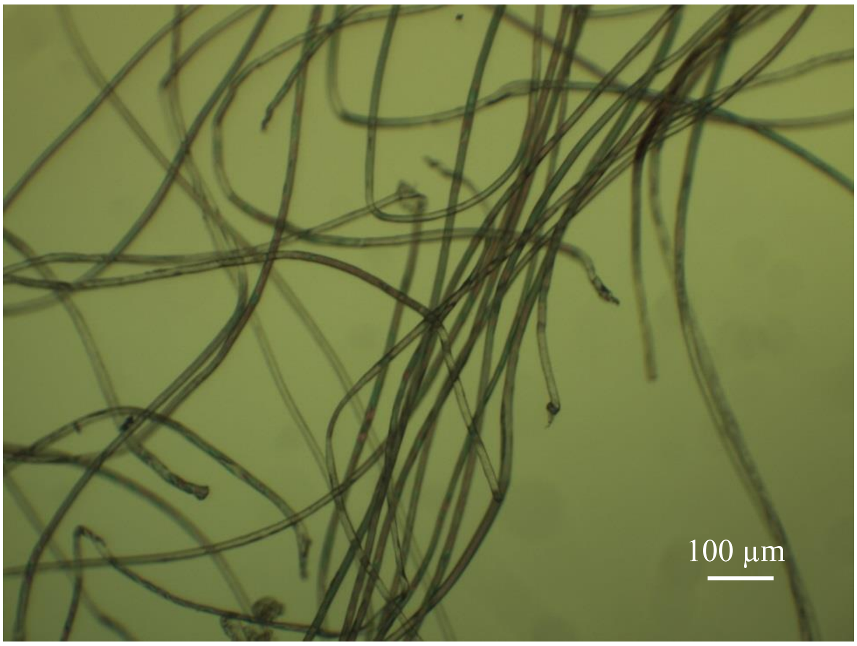


Figure A2.3 Fibres taken from weft yarn, 100x magnification

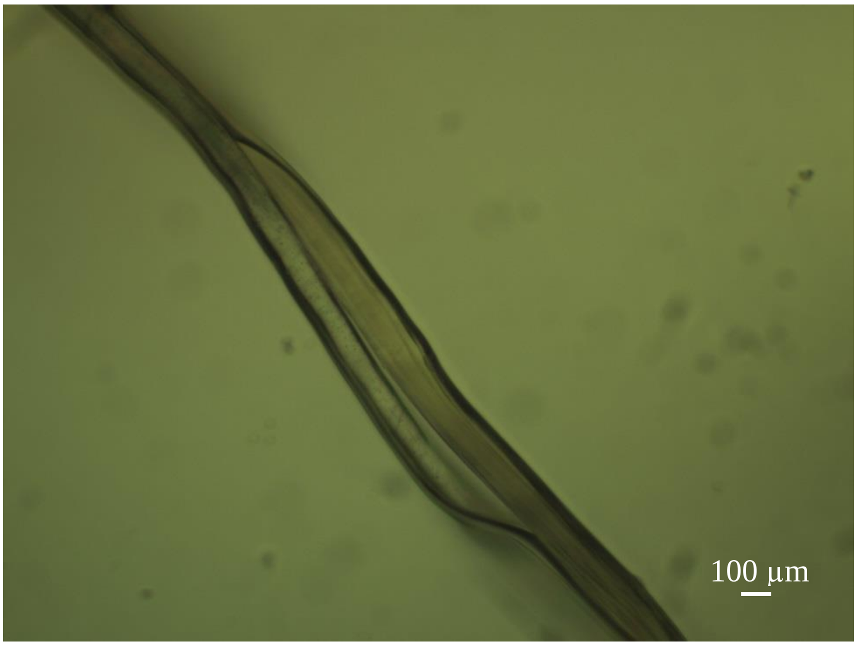


Figure A2.4 Cotton fibre taken from weft direction, 400x magnification

Appendix 3 Mass per unit area calculations

Cork material specimen 1: m = 3.9987 g

Specimen 1				Average
Width (mm)	100	100	99	99.67
Length (mm)	101	100.5	101	100.83

Mass per unit area:

$$M_{C1} = \frac{3.9987 \cdot 10^6}{(99.67 \cdot 100.83)} = 397.9\ g/m^2$$

Cork material specimen 2: m = 4.0738 g

Specimen 2				Average
Width (mm)	101.5	100	100	100.5
Length (mm)	100	100	101	100.33

Mass per unit area:

$$M_{C2} = \frac{4.0738 \cdot 10^6}{(100.5 \cdot 100.33)} = 404.0\ g/m^2$$

Cork material specimen 3: m = 4.0356 g

Specimen 3				Average
Width (mm)	100	100	99.5	99.83
Length (mm)	101	100	100	100.33

Mass per unit area:

$$M_{C3} = \frac{4.0356 \cdot 10^6}{(99.83 \cdot 100.33)} = 402.9\ g/m^2$$

Cork material specimen 4: m = 4.0399 g

Specimen 4				Average
Width (mm)	100	100	100.5	100.17
Length (mm)	100	100	101	100.33

Mass per unit area:

$$M_{C4} = \frac{4.0399 \cdot 10^6}{(100.17 \cdot 100.33)} = 402.0\ g/m^2$$

Cork material specimen 5: m = 4.0560 g

Specimen 5				Average
Width (mm)	100	100	101	100.33
Length (mm)	100.5	101	101	100.83

Mass per unit area:

$$M_{C5} = \frac{4.0560 \cdot 10^6}{(100.33 \cdot 100.83)} = 400.9\ g/m^2$$

PU covered fabric specimen 1: m = 4.3827 g

Specimen 1				Average
Width (mm)	101	100	101	100.67
Length (mm)	101	101	101	101

Mass per unit area:

$$M_{PU1} = \frac{4.3827 \cdot 10^6}{(100.67 \cdot 101)} = 431.1\ g/m^2$$

PU covered fabric specimen 2: m = 4.4520 g

Specimen 2				Average
Width (mm)	100.5	100.5	101	100.67
Length (mm)	101	102	101	101.33

Mass per unit area:

$$M_{PU2} = \frac{4.4520 \cdot 10^6}{(100.67 \cdot 101.33)} = 436.4\ g/m^2$$

PU covered fabric specimen 3: m = 4.3924 g

Specimen 3				Average
Width (mm)	101.5	102	101	101.5
Length (mm)	101	101	100.5	100.83

Mass per unit area:

$$M_{PU3} = \frac{4.3924 \cdot 10^6}{(101.5 \cdot 100.83)} = 429.2\ g/m^2$$

PU covered fabric specimen 4: m = 4.4460 g

Specimen 4				Average
Width (mm)	101	101.5	101	101.17
Length (mm)	101.5	101	100	100.83

Mass per unit area:

$$M_{PU4} = \frac{4.4460 \cdot 10^6}{(101.17 \cdot 100.83)} = 435.8\ g/m^2$$

PU covered fabric specimen 5: m = 4.3979 g

Specimen 5				Average
Width (mm)	101.5	100	100.5	100.67
Length (mm)	101	100	100.5	100.5

Mass per unit area:

$$M_{PU5} = \frac{4.3979 \cdot 10^6}{(100.67 \cdot 100.5)} = 434.7\ g/m^2$$

Piñatex® specimen 1: m = 22.9 g

Specimen 1				Average
Width (mm)	200.5	200	199	199.83
Length (mm)	250	248	250	249.33

Mass per unit area:

$$M_{P1} = \frac{22.9 \cdot 10^6}{(249.33 \cdot 199.83)} = 459.6\ g/m^2$$

Piñatex® specimen 2: m = 22.4 g

Specimen 2				Average
Width (mm)	200	200	202	200.67
Length (mm)	249	249	249	249

Mass per unit area:

$$M_{P2} = \frac{22.4 \cdot 10^6}{(249 \cdot 200.67)} = 448.3\ g/m^2$$

Piñatex® specimen 3: m = 22.5 g

Specimen 3				Average
Width (mm)	201	200	200	200.33
Length (mm)	251	249	251	250.33

Mass per unit area:

$$M_{P3} = \frac{22.5 \cdot 10^6}{(250.33 \cdot 200.33)} = 448.7\ g/m^2$$

Leather specimen 1: m = 7.4950 g

Specimen 1			Average
A (mm)	100.50	100.45	100.475
B (mm)	99.50	99.55	99.525

Mass per unit area:

$$M_{L1} = \frac{7.4950 \cdot 10^6}{(100.475 \cdot 99.525)} = 749.52\ g/m^2$$

Leather specimen 2: m = 7.4512 g

Specimen 2			Average
A (mm)	99.50	100.12	99.81
B (mm)	99.50	99.71	99.605

Mass per unit area:

$$M_{L2} = \frac{7.4512 \cdot 10^6}{(99.81 \cdot 99.605)} = 749.50\ g/m^2$$

Leather specimen 3: m = 7.1005 g

Specimen 3			Average
A (mm)	99.50	99.50	99.5
B (mm)	100.05	100.05	100.05

Mass per unit area:

$$M_{L3} = \frac{7.1005 \ \cdot 10^6}{(99.5 \cdot 100.05)} = 713.26 \ g/m^2$$

Appendix 4 Tear load test graphics: Cork material

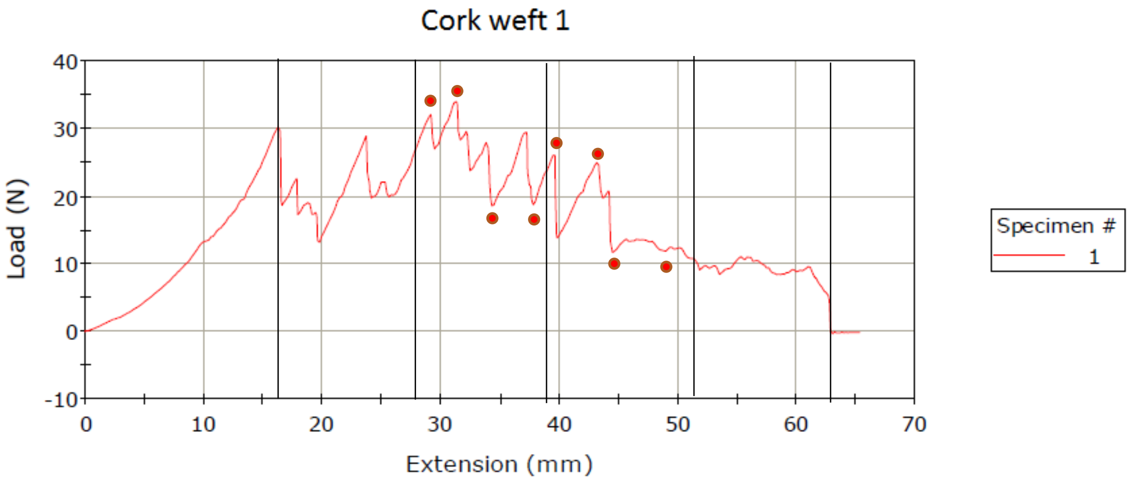


Figure A4.1 Cork sample 1, weft direction

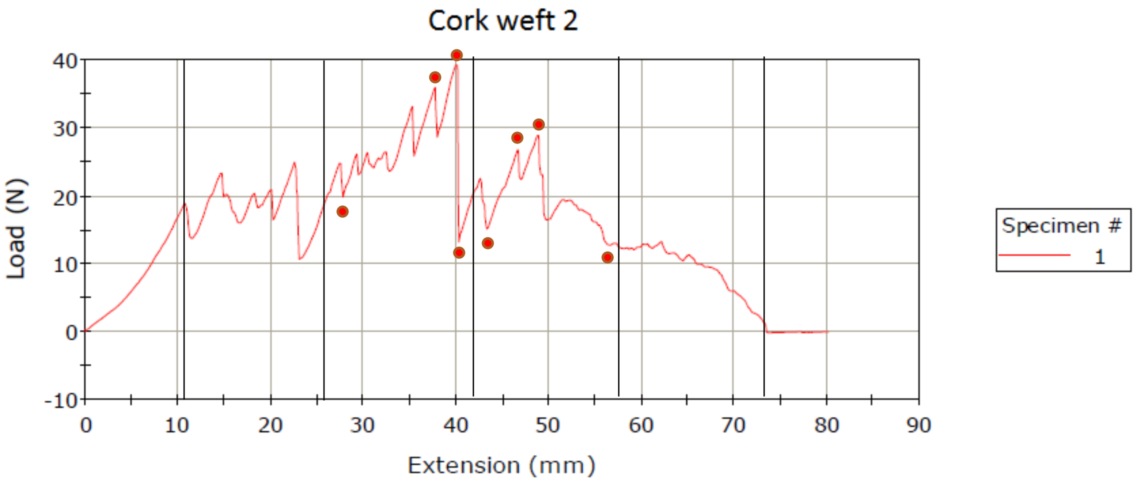


Figure A4.2 Cork sample 2, weft direction

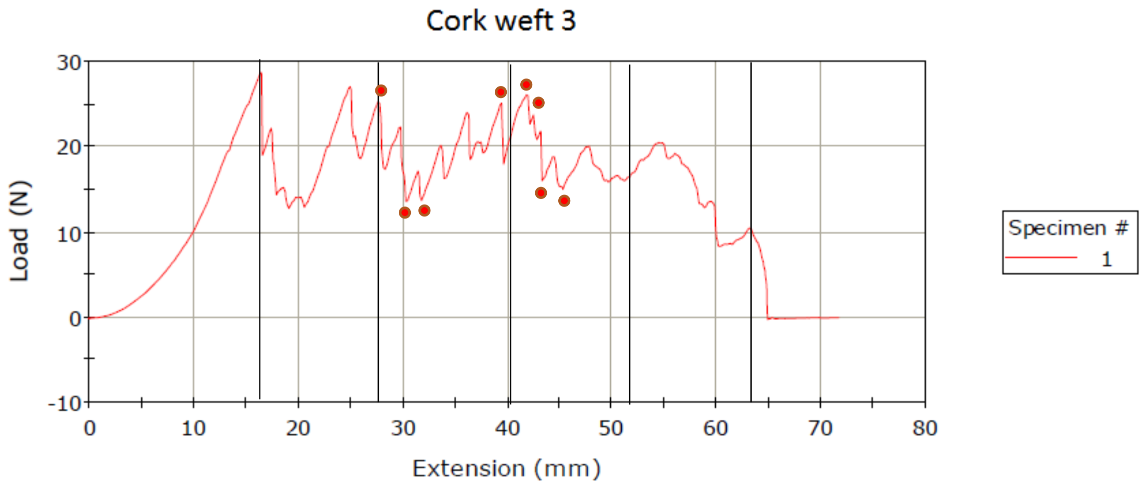


Figure A4.3 Cork sample 3, weft direction

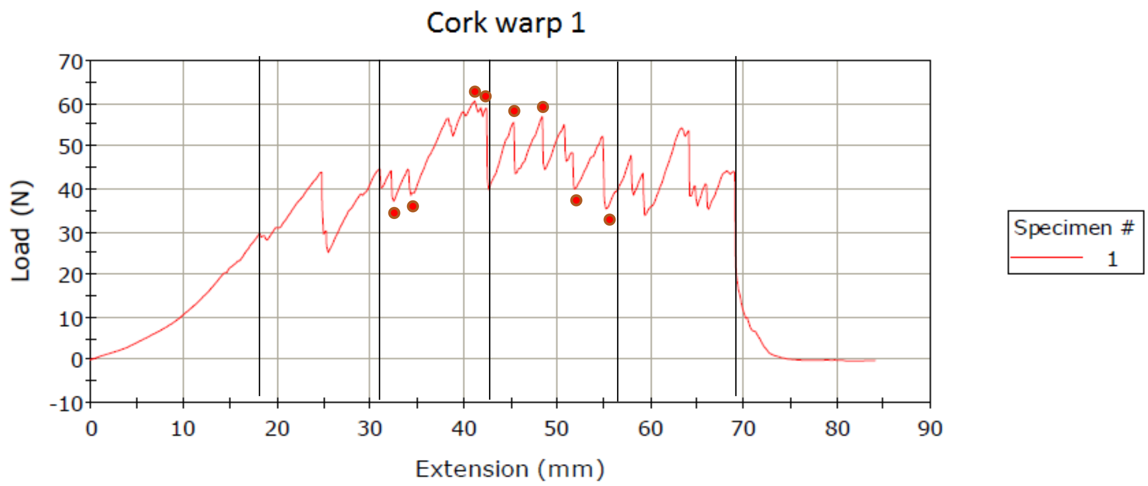


Figure A4.4 Cork sample 1, warp direction

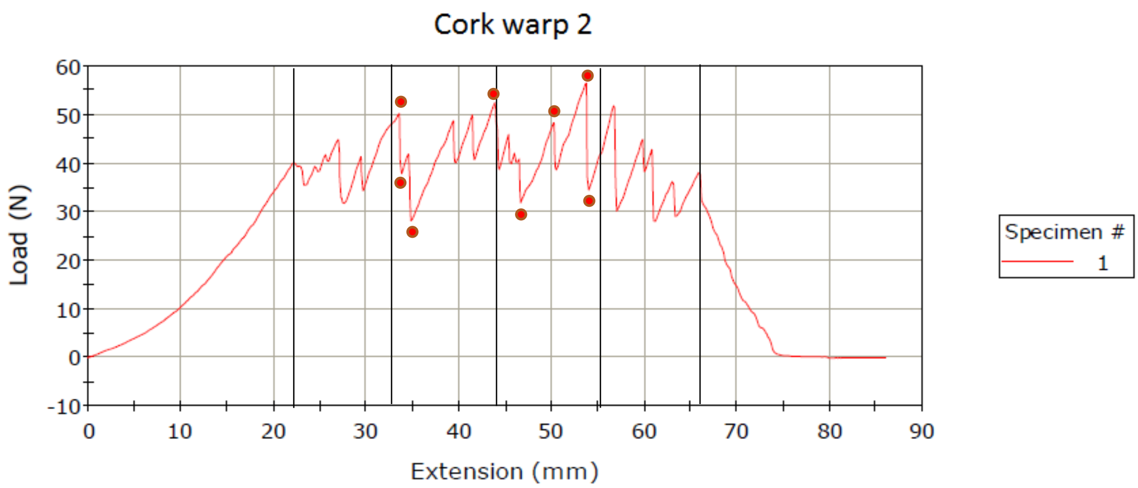


Figure A4.5 Cork sample 2, warp direction

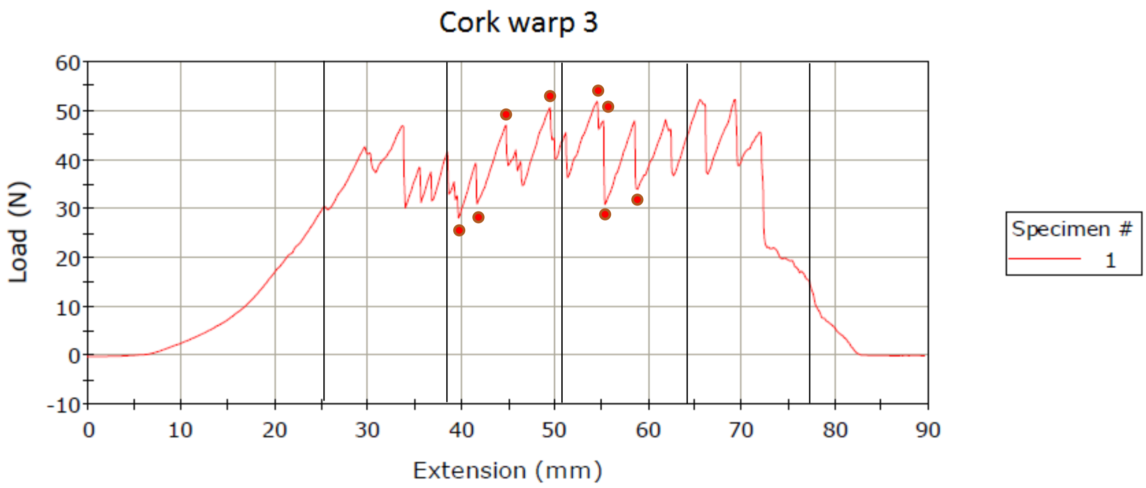


Figure A4.6 Cork sample 3, warp direction

Appendix 5 Tear load test graphics: Piñatex® material

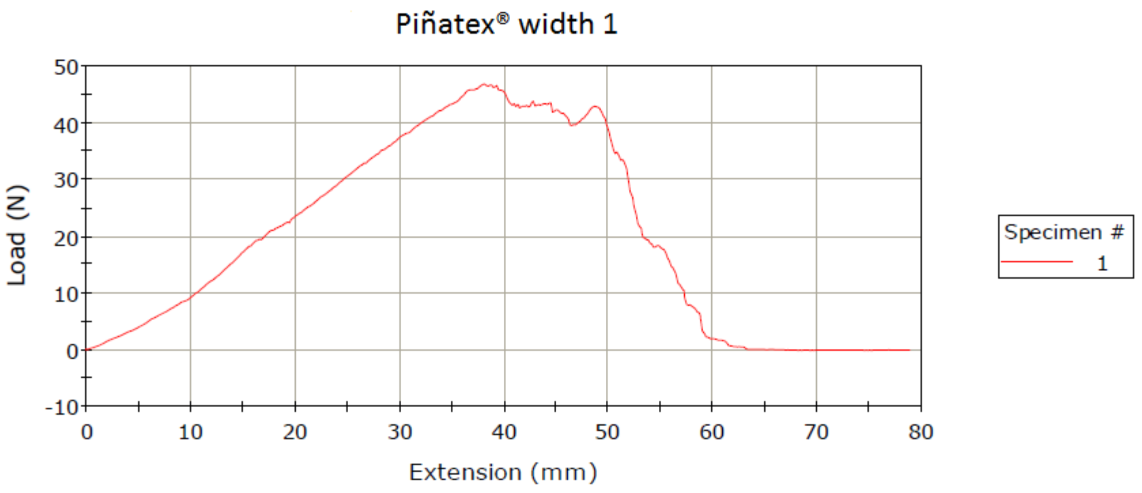


Figure A5.1 Piñatex® sample 1, width direction

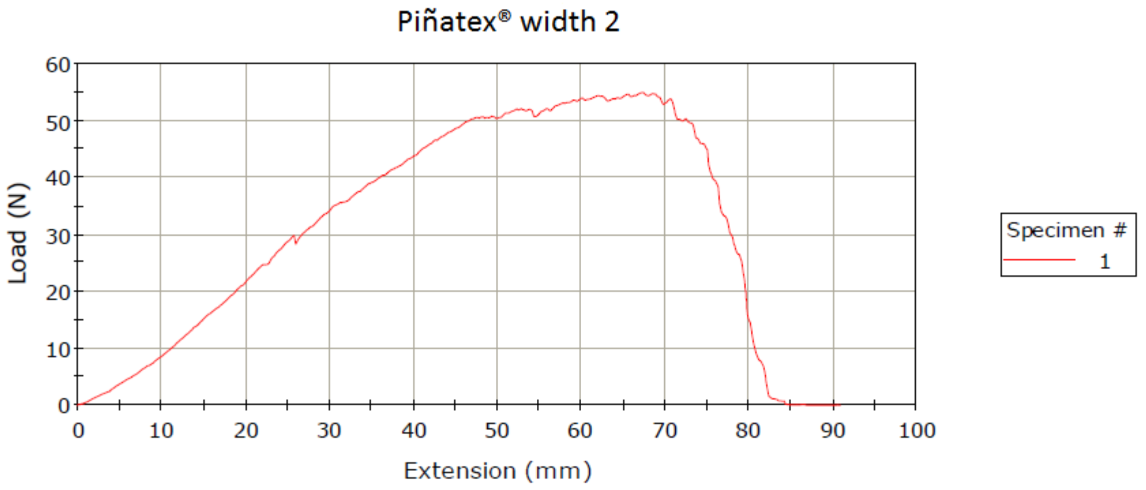


Figure A5.2 Piñatex® sample 2, width direction

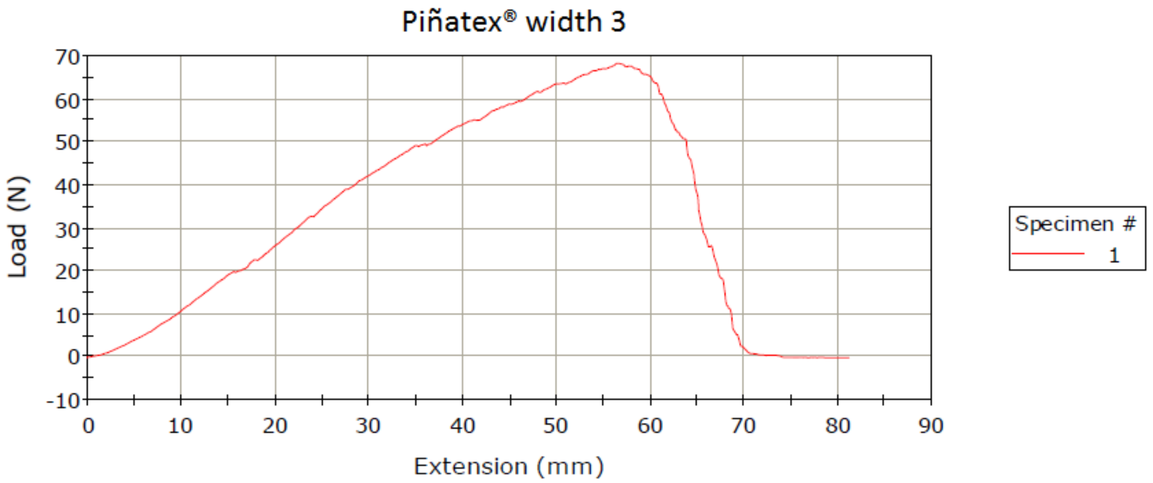


Figure A5.3 Piñatex® sample 3, width direction

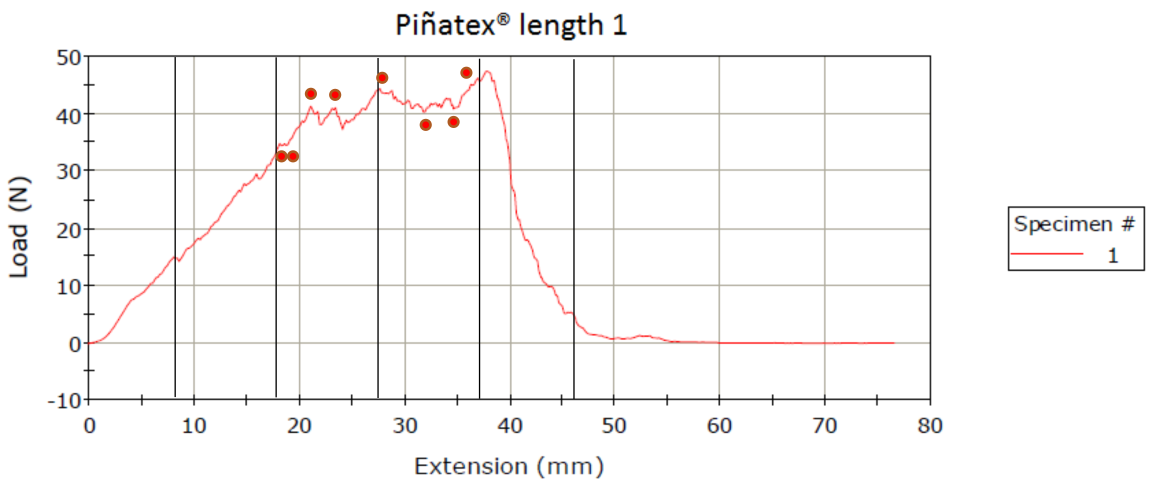


Figure A5.4 Piñatex® sample 1, length direction

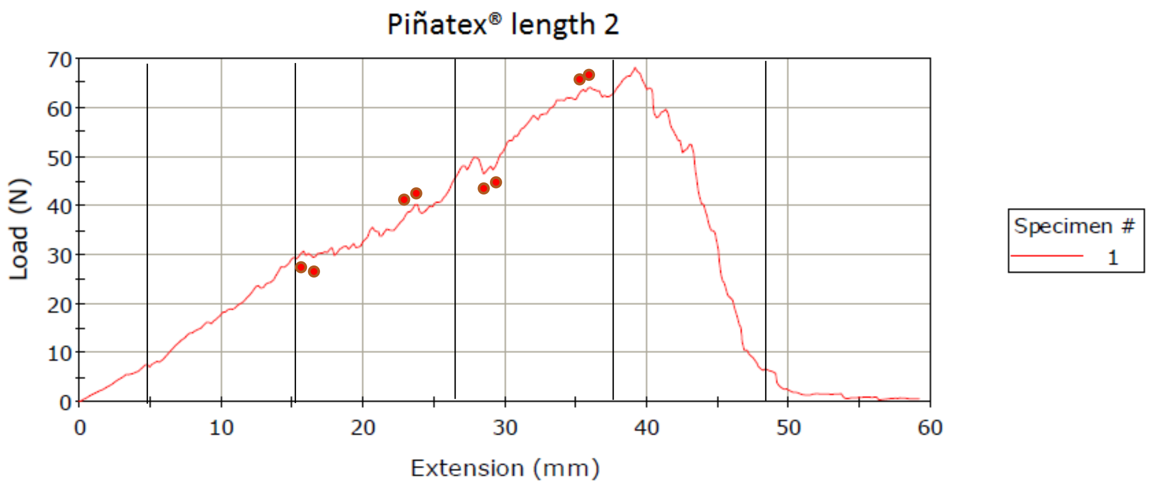


Figure A5.5 Piñatex® sample 2, length direction

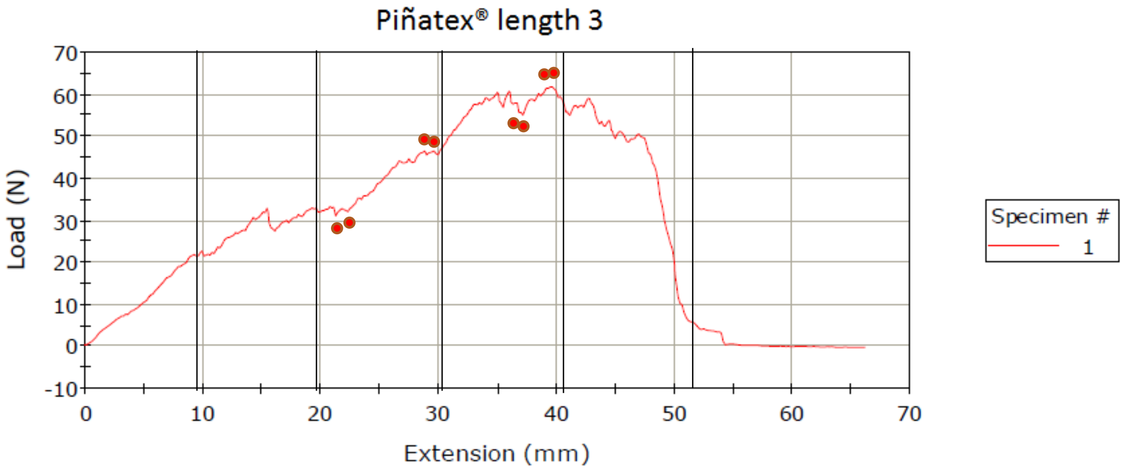


Figure A5.6 Piñatex® sample 3, length direction

Appendix 6 Tear load test graphics: PU covered fabric

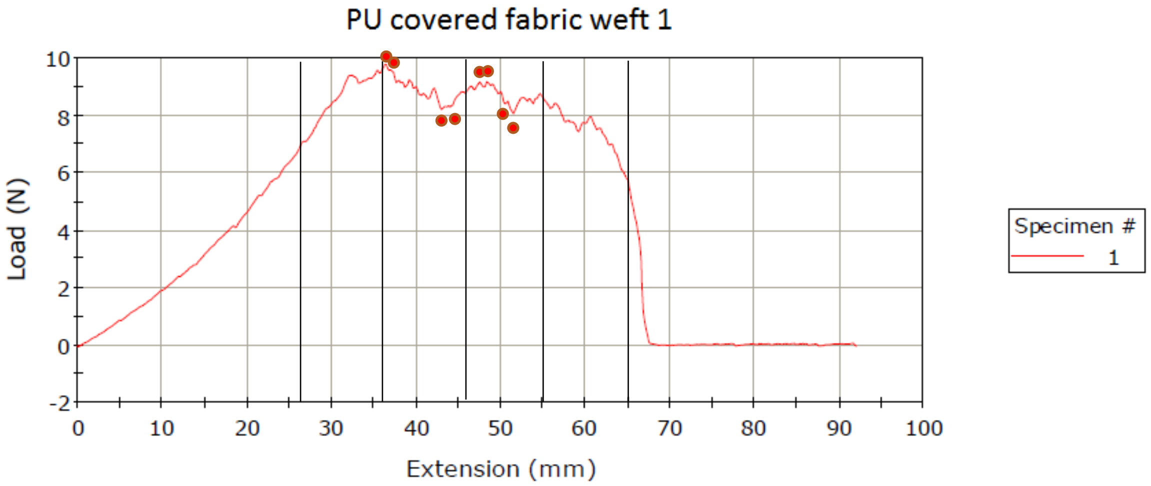


Figure A6.1 PU covered fabric sample 1, weft direction

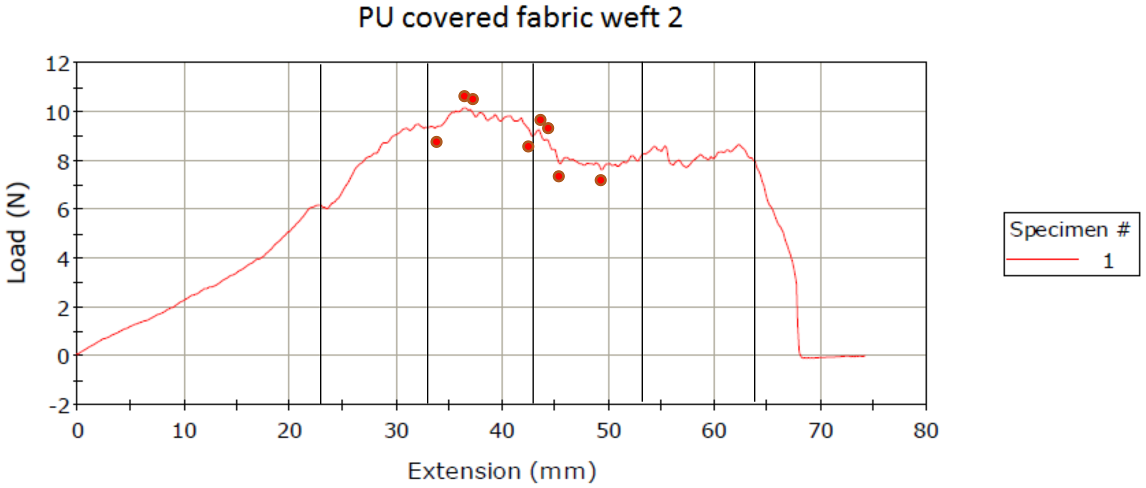


Figure A6.2 PU covered fabric sample 2, weft direction

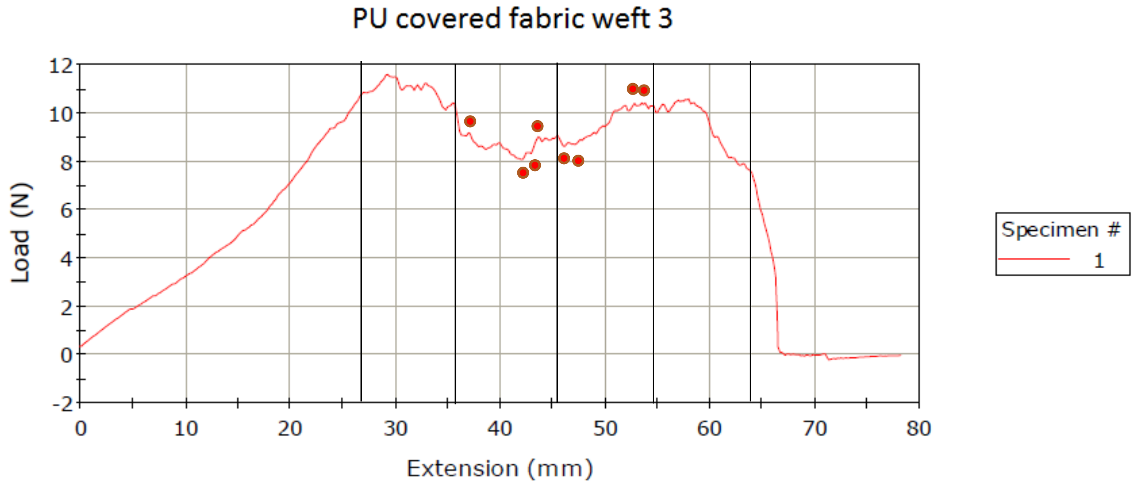


Figure A6.3 PU covered fabric sample 3, weft direction

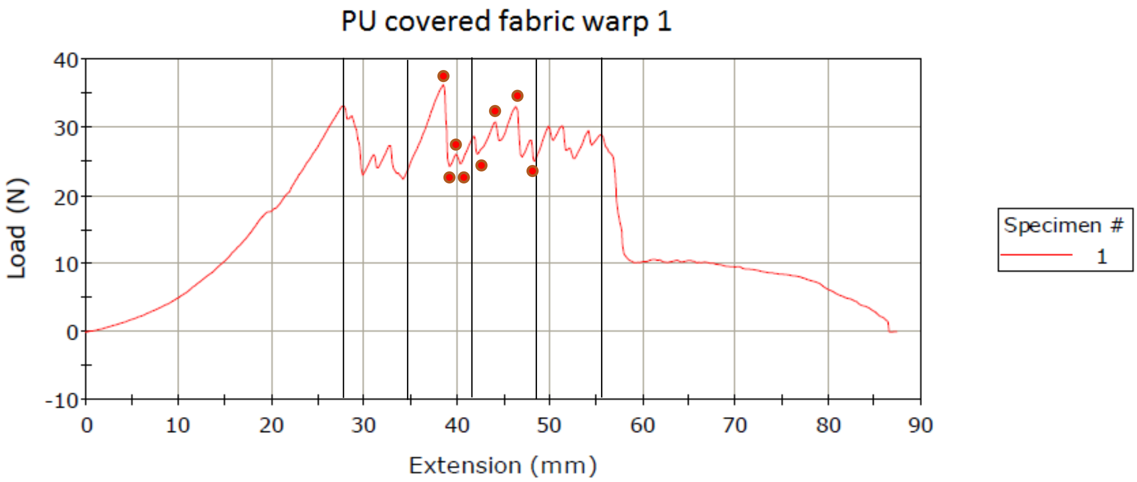


Figure A6.4 PU covered fabric sample 1, warp direction

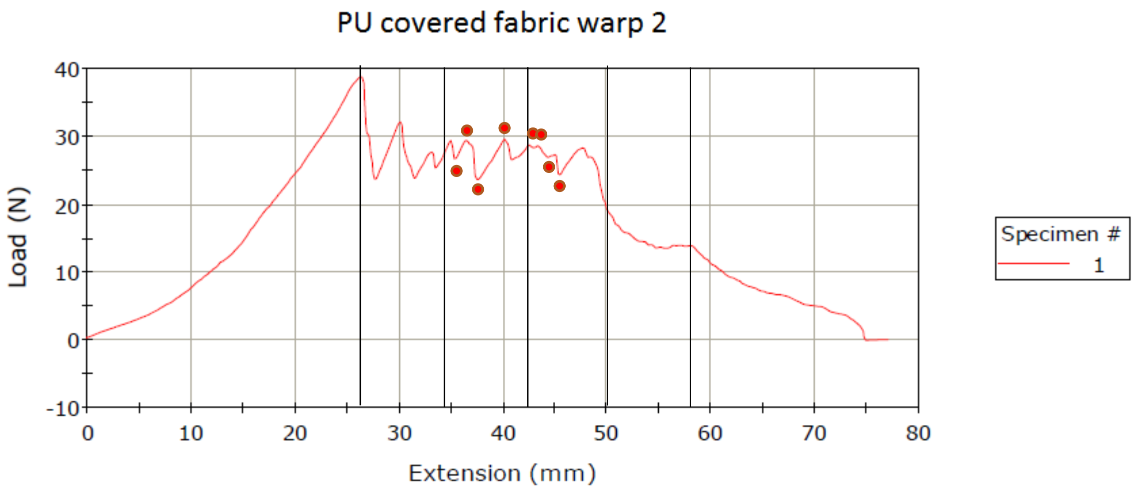


Figure A6.5 PU covered fabric sample 2, warp direction

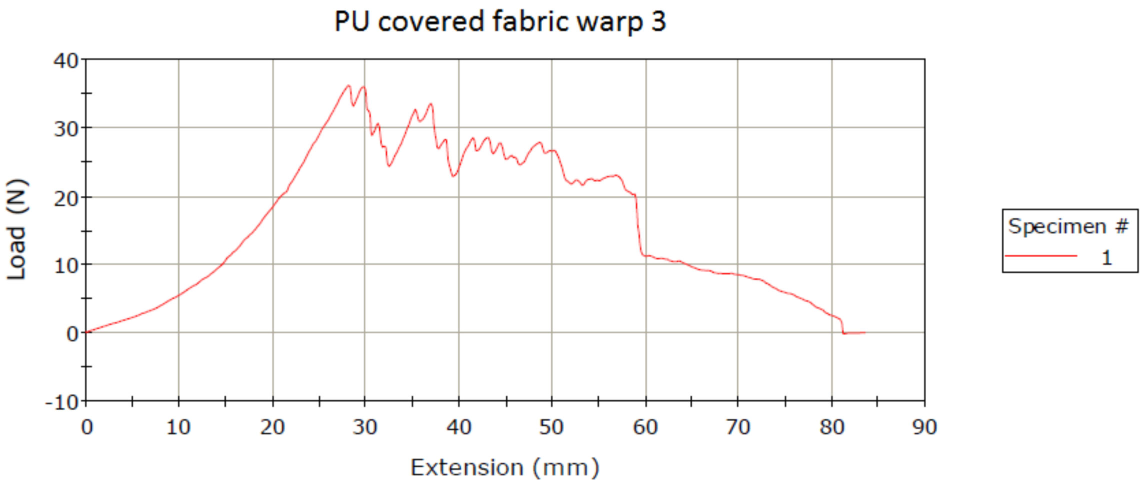


Figure A6.6 PU covered fabric sample 3, warp direction

Appendix 7 Tear load test graphics: Vegetable tanned leather

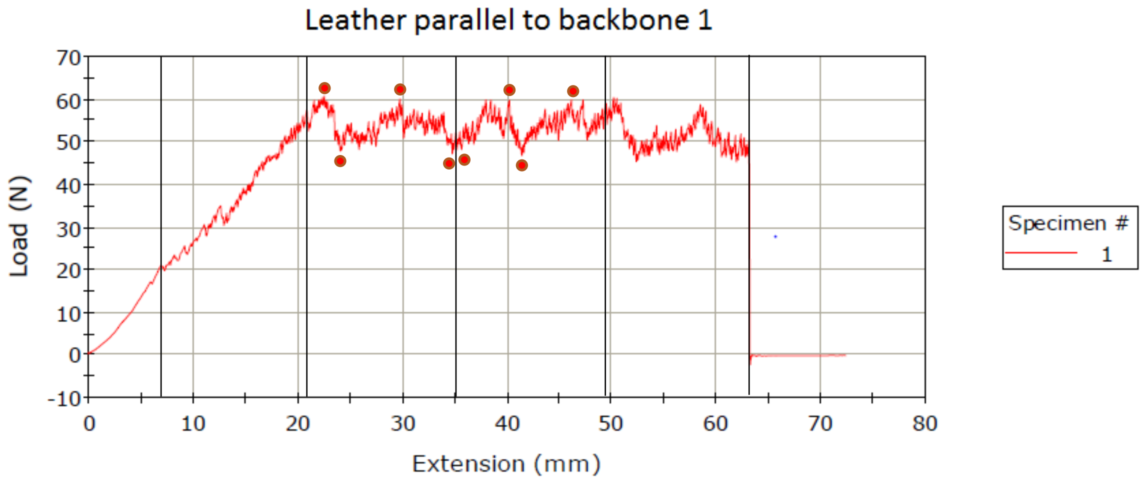


Figure A7.1 Leather sample 1, parallel to backbone

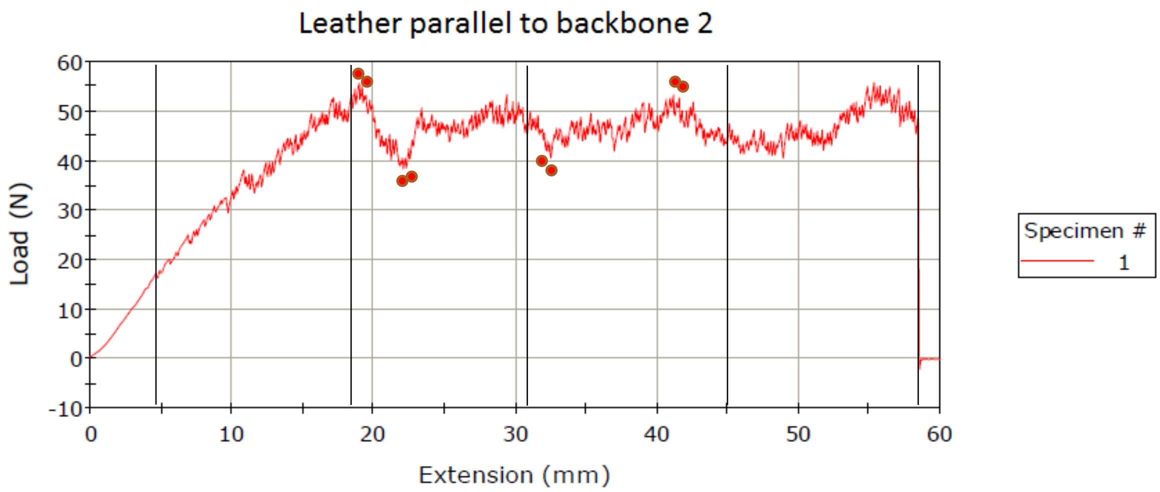


Figure A7.2 Leather sample 2, parallel to backbone

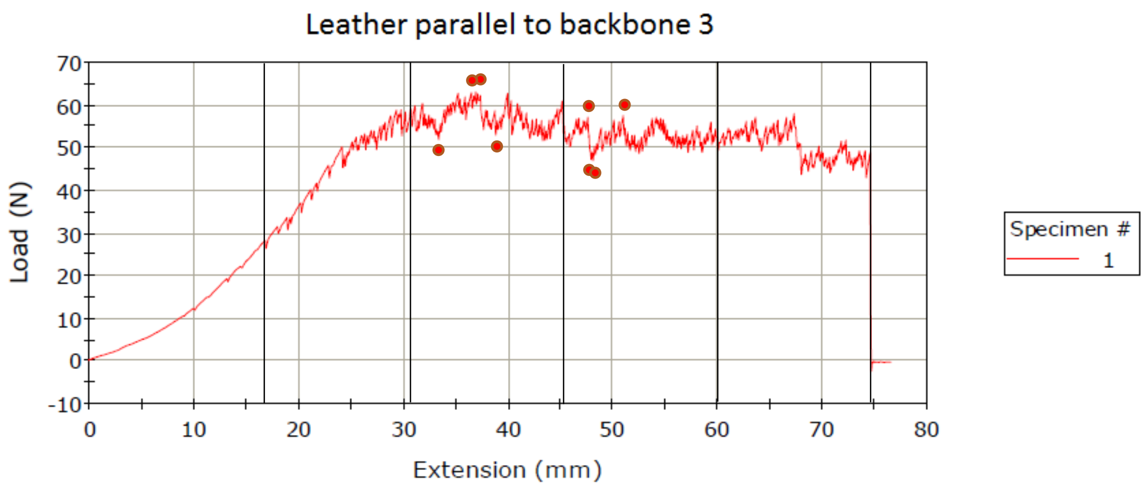


Figure A7.3 Leather sample 3, parallel to backbone

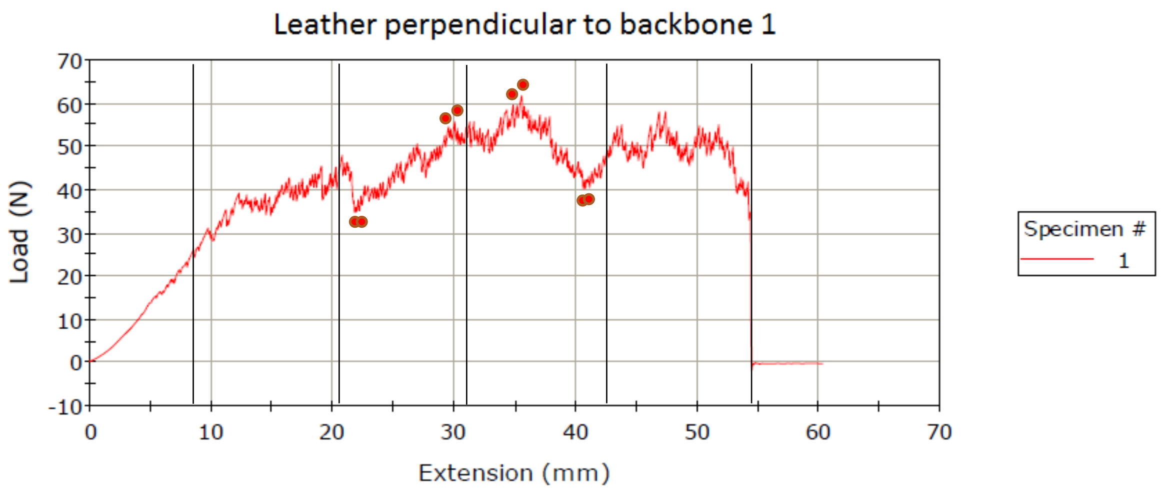


Figure A7.4 Leather sample 1, perpendicular to backbone

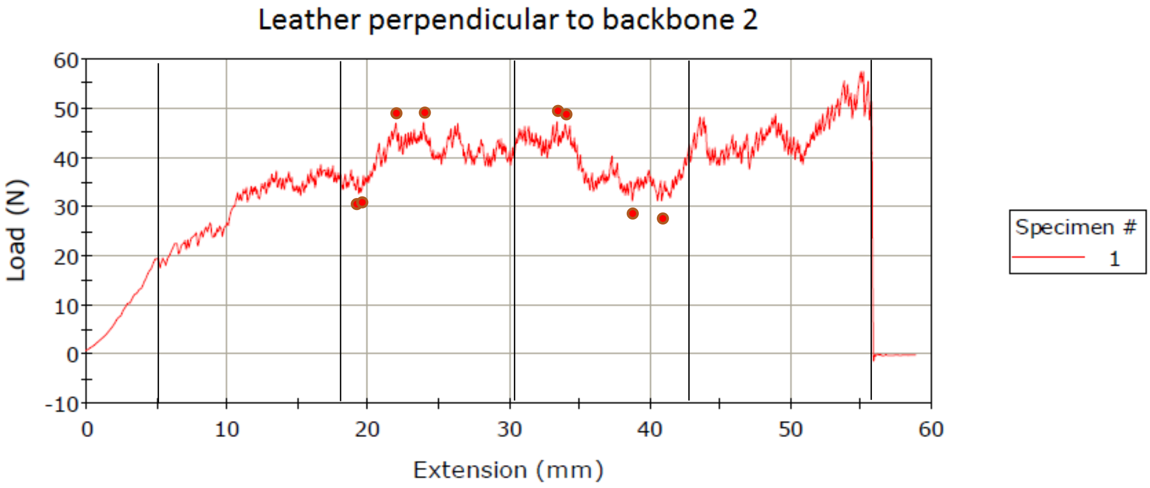


Figure A7.5 Leather sample 2, perpendicular to backbone

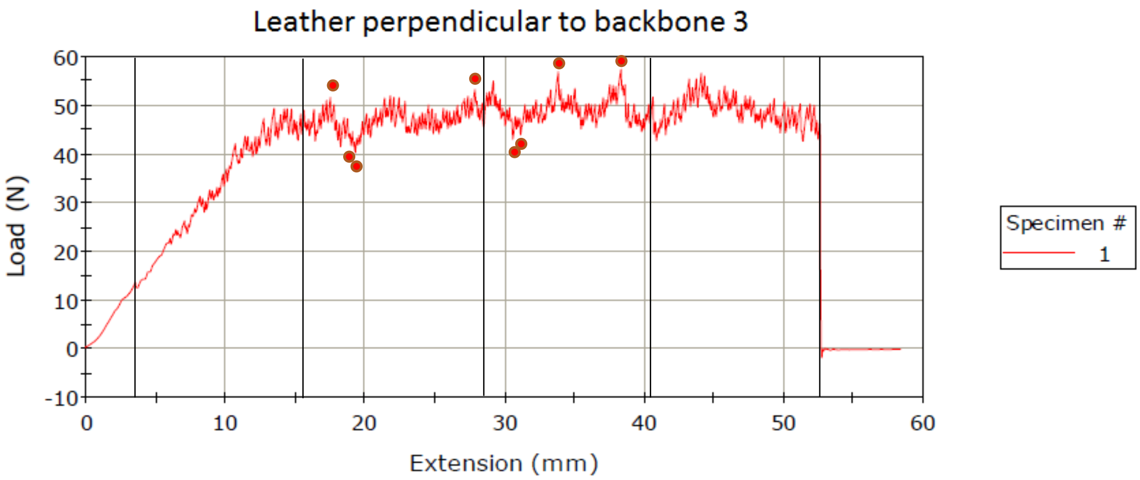


Figure A7.6 Leather sample 3, perpendicular to backbone

Appendix 8 Tear load test results

Table A8.1 Cork material tear load test results

Cork Material						**Sample average, N**	**Average, N**
Weft direction							
1	Highest peaks	31.43030344	33.70218063	26,00093993	24.97679224	22.126922	21.9±2.1
	Lowest valleys	18.5636158	18.76664287	11,67358119	11.90132102		
2	Highest peaks	35.80761935	39.13495686	26,64897317	28.82819713	23.93112	
	Lowest valleys	19.83665626	13.22709184	15,18933386	12.77613304		
3	Highest peaks	24.97088864	24.47683942	25,91207207	23.05105058	19.610787	
	Lowest valleys	13.70005676	13.70155718	16,03558891	15.0382428		
Warp direction							
4	Highest peaks	60.5843069	58.70581367	55,49601868	56.66132328	47.846748	43.4±4.0
	Lowest valleys	37.24795146	38.57428126	40,0451905	35.45910082		
5	Highest peaks	49.43906879	52.51891587	48,0893109	56.18955477	42.343836	
	Lowest valleys	37.89163054	28.1853516	31,93479675	34.50206004		
6	Highest peaks	46.54488121	49.97477666	51,5241391	47.77099685	39.970661	
	Lowest valleys	28.11027189	30.95887816	30,90717751	33.97416807		
Average							**32.6±12.1**

Table A8.2 Piñatex® material tear load test results

Piñatex® Material						**Sample average, N**	**Average, N**
Width direction							
1	Highest peaks	Results not suitable for calculation				-	-
	Lowest valleys						
2	Highest peaks	Results not suitable for calculation				-	
	Lowest valleys						
3	Highest peaks	Results not suitable for calculation				-	
	Lowest valleys						
Length direction							
4	Highest peaks	41.01717661	40.97863648	44.31575121	44.8762699	40.133313	
	Lowest valleys	34.40358166	34.43605148	40.23152665	40.80751043		

Table A8.2 Piñatex® material tear load test results

Piñatex® Material						**Sample average, N**	**Average, N**
5	Highest peaks	38.78158403	40.23639075	63.83380903	63.23793736		44.6±4.3
	Lowest valleys	29.482928.1	29.84379341	46.51343128	47.32334289	44.906652	
6	Highest peaks	46.54741132	46.48702197	61.54544686	61.71544514		
	Lowest valleys	31.12794481	32.18146341	55.69266162	55.0537976	48.793899	
Average							**44.6±4.3**

Table A8.3 PU coated fabric tear load test results

PU coated fabric						**Sample average, N**	**Average, N**
Weft direction							
1	Highest peaks	9.610898479	9.528816818	9.090246759	9.128366188		8.9±0.1
	Lowest valleys	8.203949191	8.282753469	8.392676208	8.054791025	8.7865623	
2	Highest peaks	10.13460399	9.989249823	9.232684427	8.822280048		
	Lowest valleys	9.307728836	9.007626713	7.860532075	7.626756249	8.9976828	
3	Highest peaks	9.134160938	8.943006774	10.38956708	10.33944529		
	Lowest valleys	8.074484739	8.314103367	8.600272202	8.682534304	9.0596968	
Warp direction							
4	Highest peaks	36.2239901	25.88680033	30.70990693	32.44208494		27.4±0.5
	Lowest valleys	24.23429155	24.60104064	24.60104064	24.9966409	27.961975	
5	Highest peaks	29.19393614	29.22671977	28.45513255	28.57117464		
	Lowest valleys	26.69307367	23.69200341	26.90609373	24.36122882	27.13742	
6	Highest peaks	32.98940389	28.56907601	27.73903135	27.69858873		
	Lowest valleys	22.86885283	26.6532881	25.41861125	24.56705079	27.062988	
Average							**18.2±10.1**

Table A8.4 Vegetable-tanned leather tear load test results

Vegetable-tanned leather						**Sample average, N**	**Average, N**
Parallel to the backbone							
1	Highest peaks	60.67535184	59.61225214	59,5936097	59.57666381		51.9±4.3
	Lowest valleys	47.86860244	47.19892592	48,20805963	46.82829339	53.69522	
2	Highest peaks	55.63236053	55.27417264	53,16967536	52.65328659		
	Lowest valleys	38.32963225	38.51215613	40,57704435	41.93380419	47.010267	
3	Highest peaks	63.06023105	62.81955625	57,1310324	57.2717186		
	Lowest valleys	51.9264373	52.95419384	47,25278405	47.02551493	54.930184	
Perpendicular to the backbone							
4	Highest peaks	54.0511559	55.36706123	58,91641148	61.34087034		45.0±4.9
	Lowest valleys	34.87894921	34.89211954	40,25259134	40.30794007	47.500887	
5	Highest peaks	46.5879324	46.82572405	45,89483761	47.29098095		
	Lowest valleys	32.71973082	32.99022765	31,221333354	31.23166975	39.345305	
6	Highest peaks	51.64469225	51.68922425	56,5321599	57.37221715		
	Lowest valleys	41.17322003	40.30839117	43,0553221	43.96598723	48.217652	
Average							**48.4±5.6**

Appendix 9 Air permeability test results

Table A9.1 Results of air permeability test

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Piñatex®, $\frac{l}{m^2 \cdot s}$	7.07	6.33	6.42	6.65	6.07	6.34	6.33	5.6	6.68	6.34
Average	**(6.38±0.39)** $\frac{l}{m^2 \cdot s}$									
Cork, $\frac{l}{m^2 \cdot s}$	0.828	0.750	0.748	0.744	0.750	0.736	0.778	0.737	0.760	0.764
Average	**(0.76±0.03)** $\frac{l}{m^2 \cdot s}$									
Leather, $\frac{l}{m^2 \cdot s}$	2.15	1.89	1.55	1.50	1.40	1.90	2.28	1.43	1.49	1.41
Average	**(1.70±0.33)** $\frac{l}{m^2 \cdot s}$									
PU covered fabric, $\frac{l}{m^2 \cdot s}$	0.476	0.501	0.517	0.523	0.527	0.500	0.556	0.554	0.555	0.517
Average	**(0.52±0.03)** $\frac{l}{m^2 \cdot s}$									

Appendix 10 Abrasion test photos

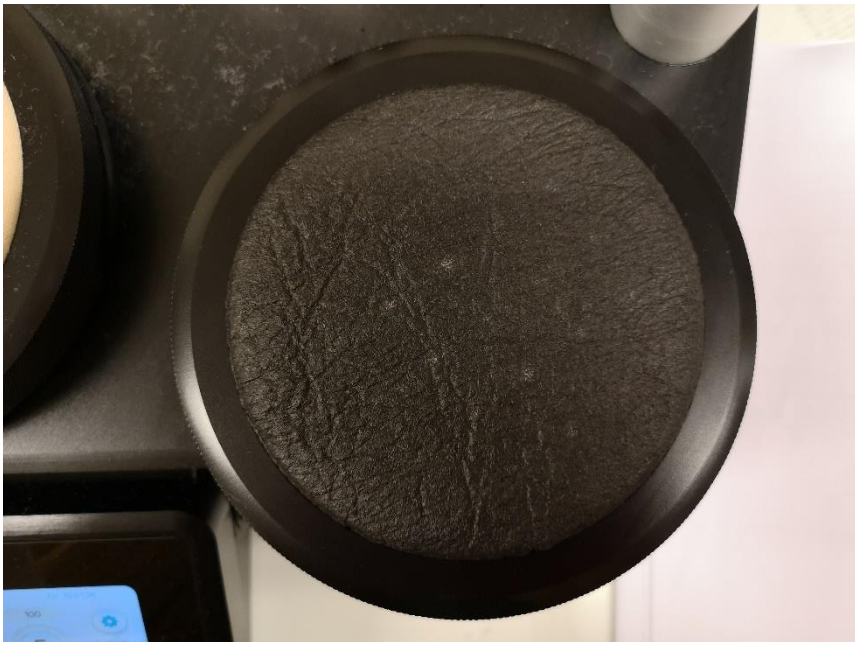


Figure A10.1 The first sample of Piñatex® material after 100 rubs

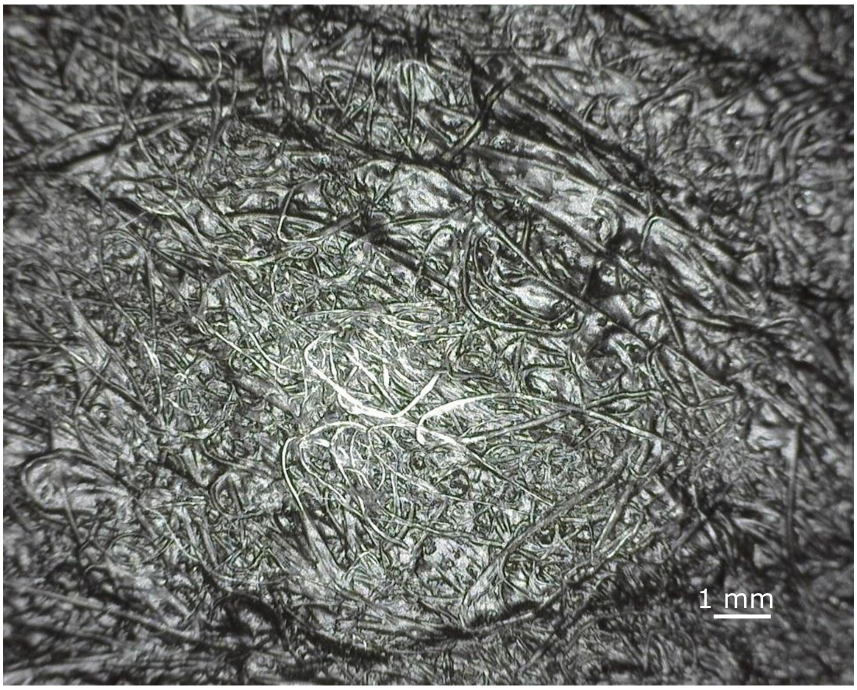


Figure A10.2 The first sample of Piñatex® material after 100 rubs seen through a microscope

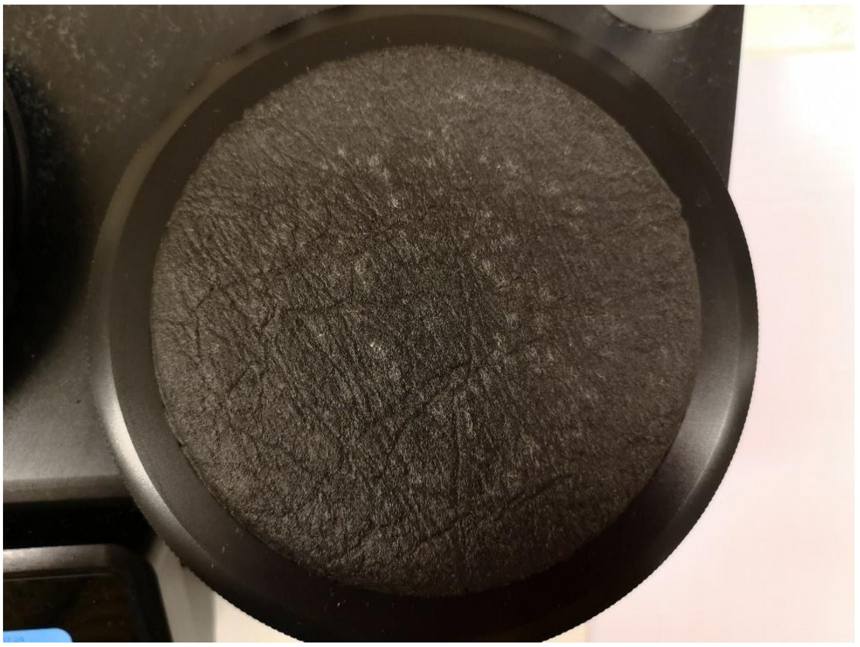


Figure A10.3 The first sample of Piñatex® material after 1000 rubs

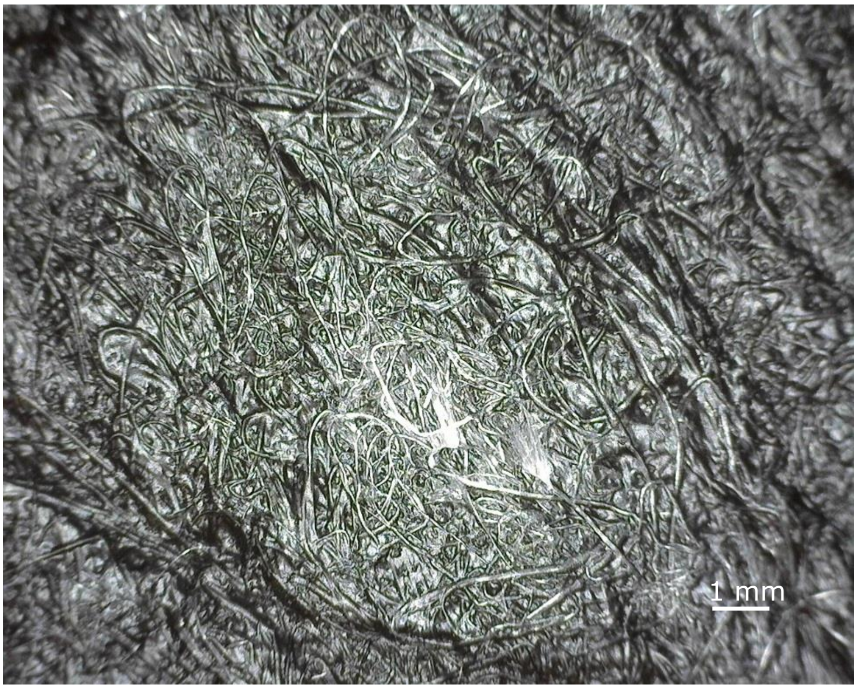


Figure A10.4 The first sample of Piñatex® material after 1000 rubs seen through a microscope

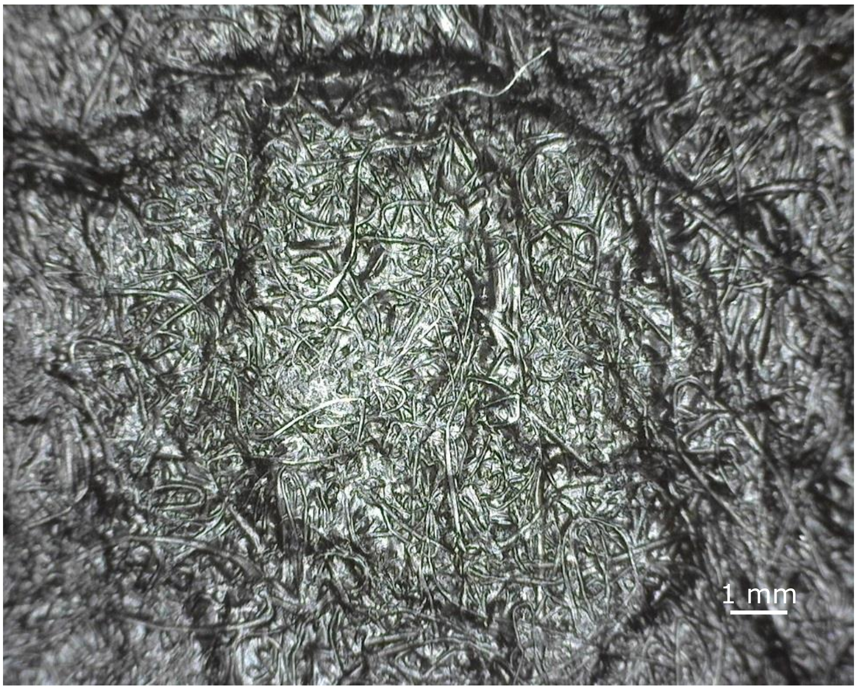


Figure A10.5 The second sample of Piñatex® material after 100 rubs seen through a microscope

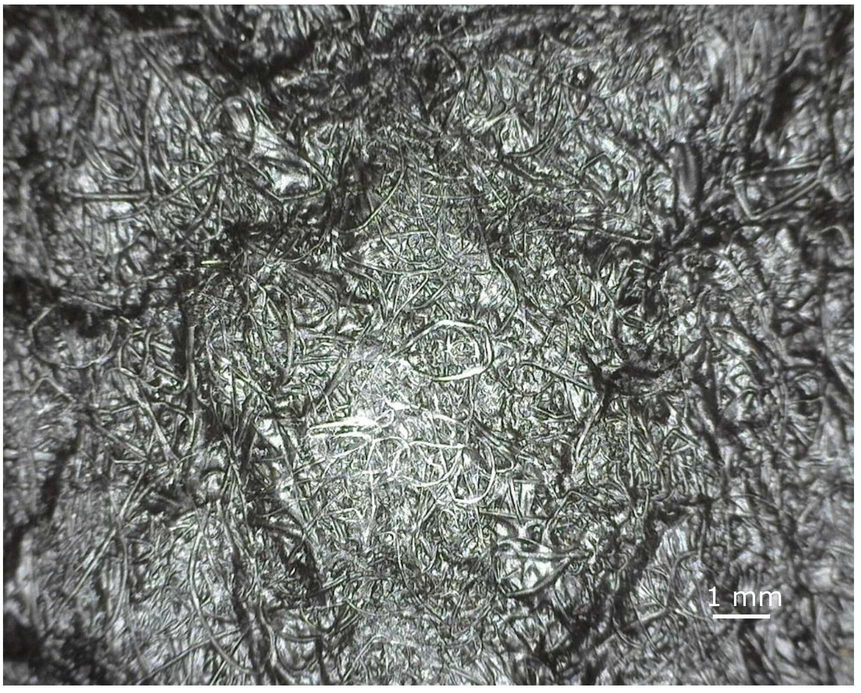


Figure A10.6 The second sample of Piñatex® material after 1000 rubs seen through a microscope

Figure A10.7 The first sample of cork material after 100 rubs

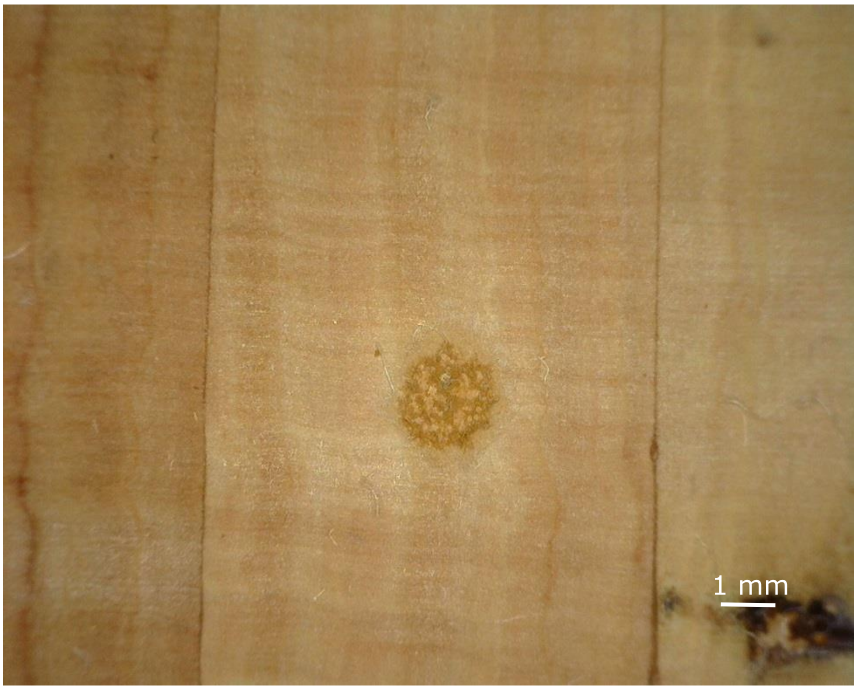


Figure A10.8 The first sample of cork material after 100 rubs seen through a microscope

Figure A10.9 The first sample of cork material after 200 rubs

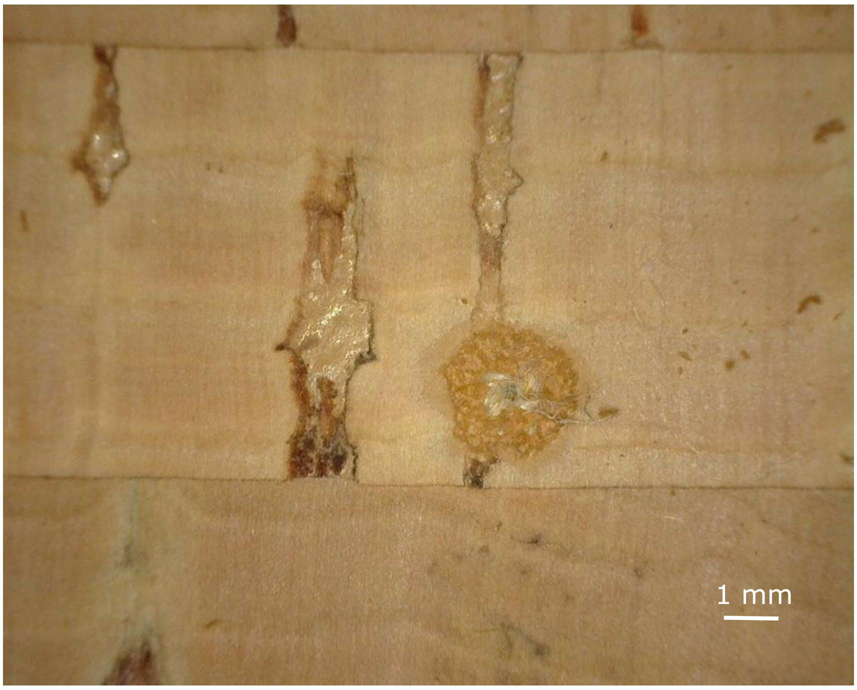


Figure A10.10 The first sample of cork material after 200 rubs seen through a microscope

Figure A10.11 The second sample of cork material after 100 rubs seen through a microscope

Figure A10.12 The second sample of cork material after 300 rubs seen through a microscope

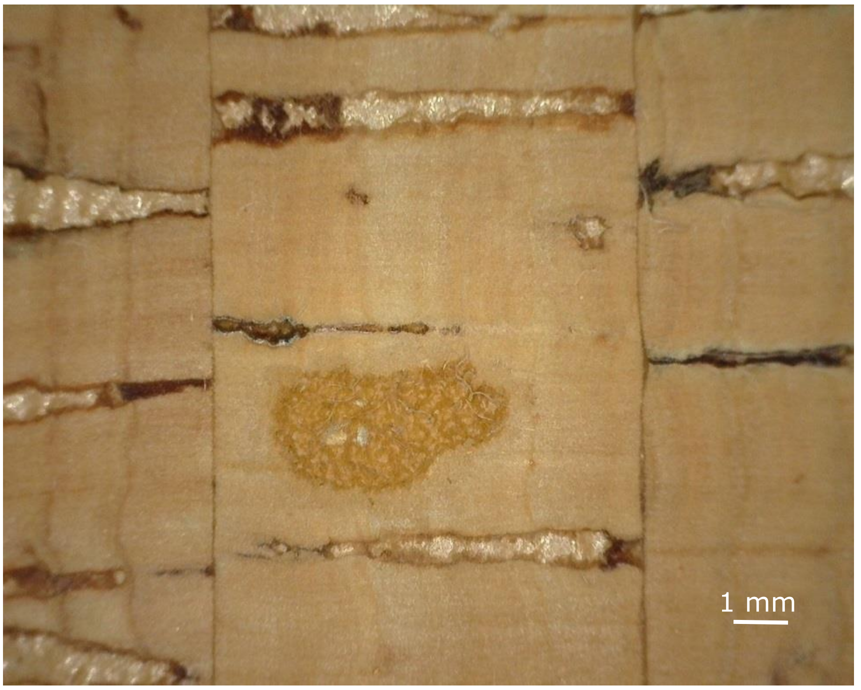


Figure A10.13 The second sample of cork material after 400 rubs seen through a microscope

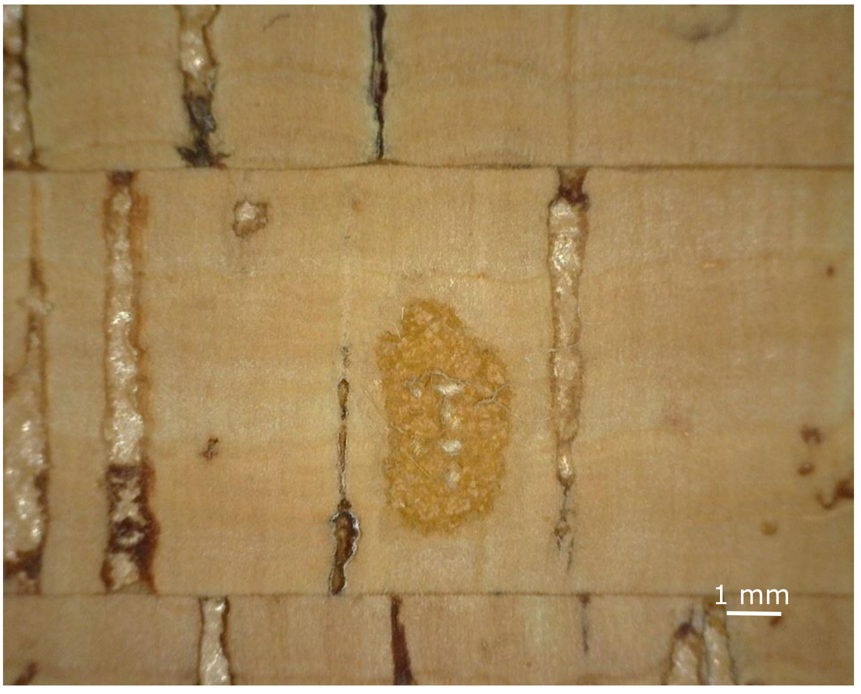


Figure A10.14 The second sample of cork material after 500 rubs seen through a microscope

Figure A10.15 The first sample of vegetable-tanned leather after 100 rubs

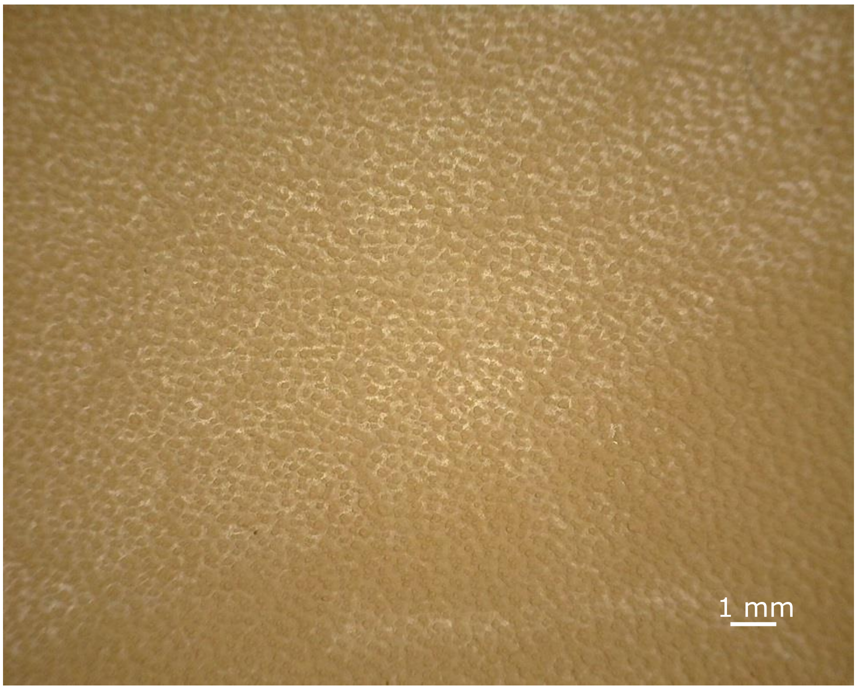


Figure A10.16 The first sample of vegetable-tanned leather after 100 rubs seen through a microscope

Figure A10.17 The first sample of vegetable-tanned leather after 1600 rubs

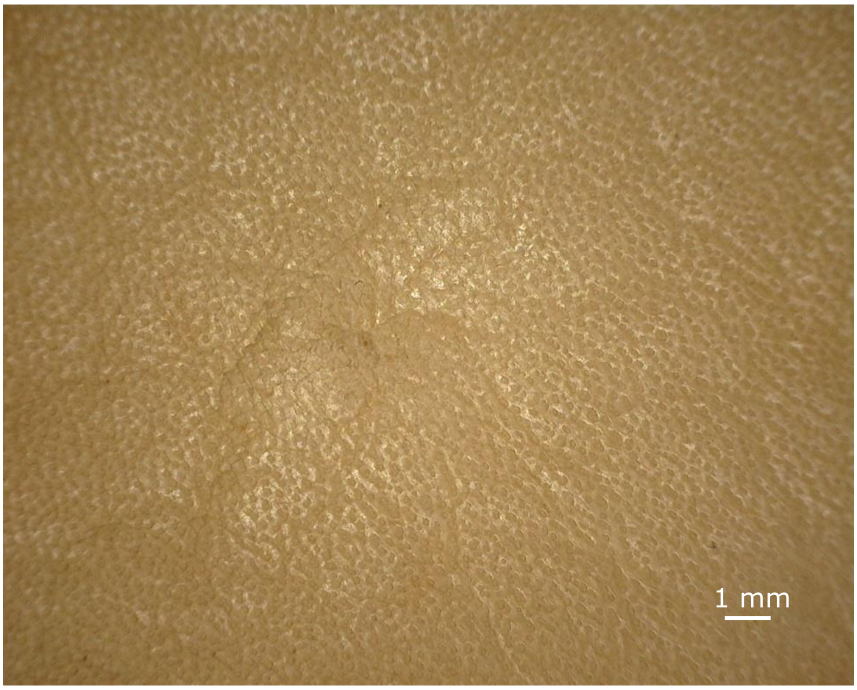


Figure A10.18 The first sample of vegetable-tanned leather after 1600 rubs seen through a microscope

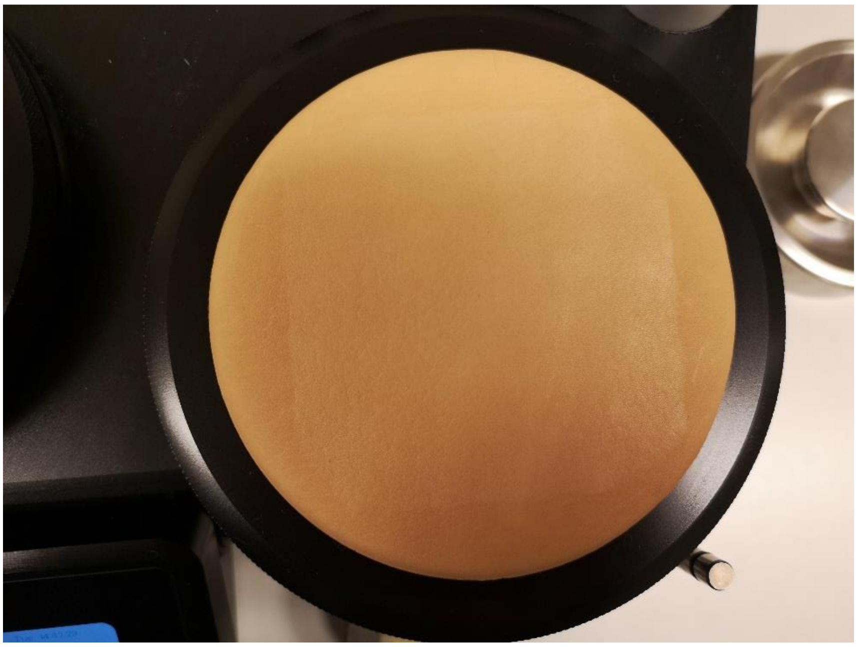


Figure A10.19 The second sample of vegetable-tanned leather after 100 rubs

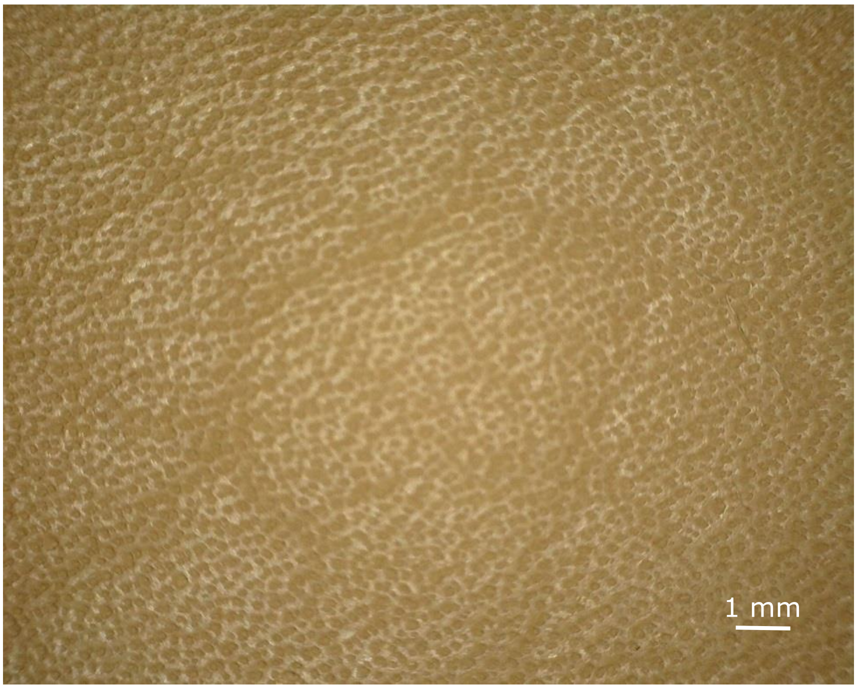


Figure A10.20 The second sample of vegetable-tanned leather after 100 rubs seen through a microscope

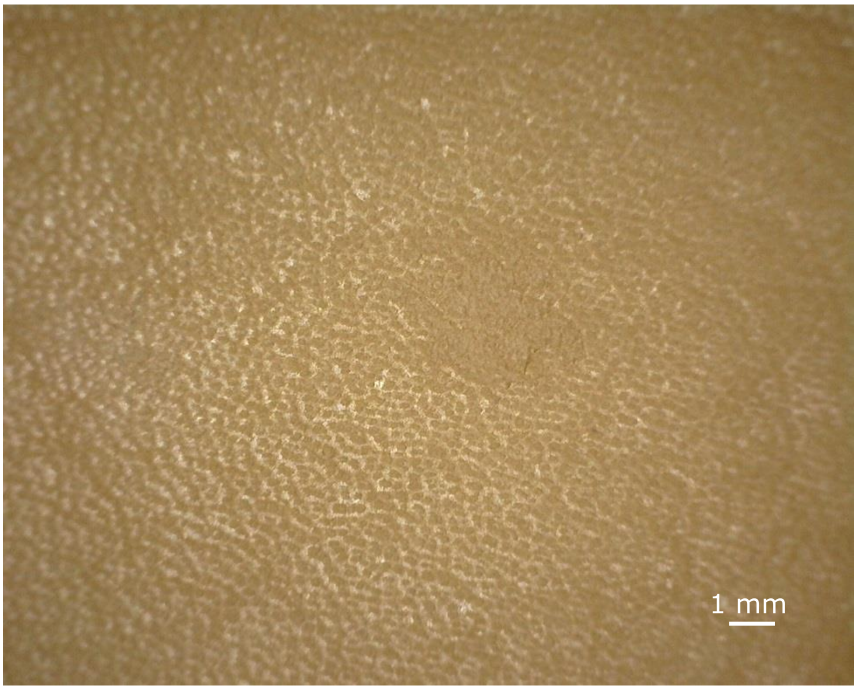


Figure A10.21 The second sample of vegetable-tanned leather after 1700 rubs seen through a microscope

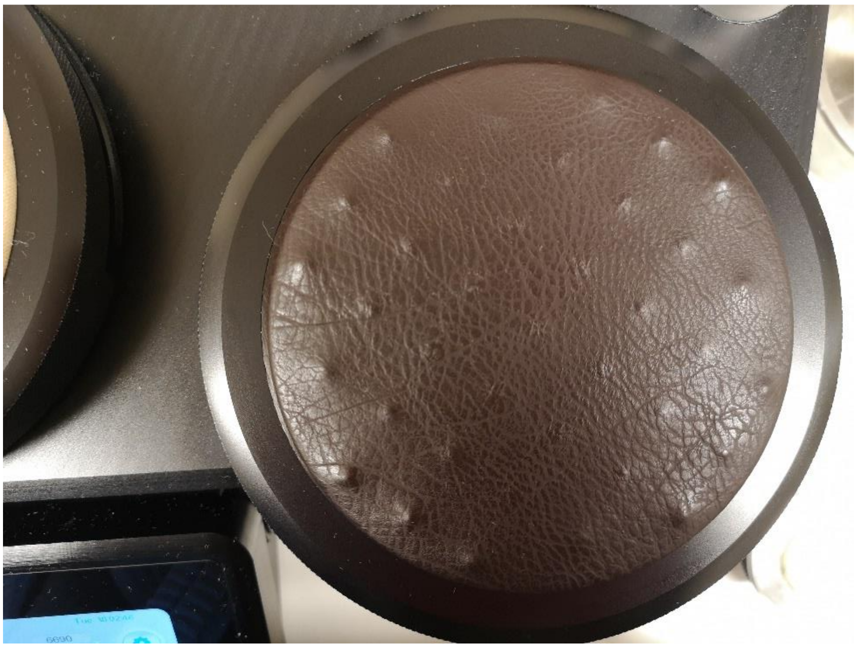


Figure A10.22 The first sample of PU covered fabric after 100 rubs

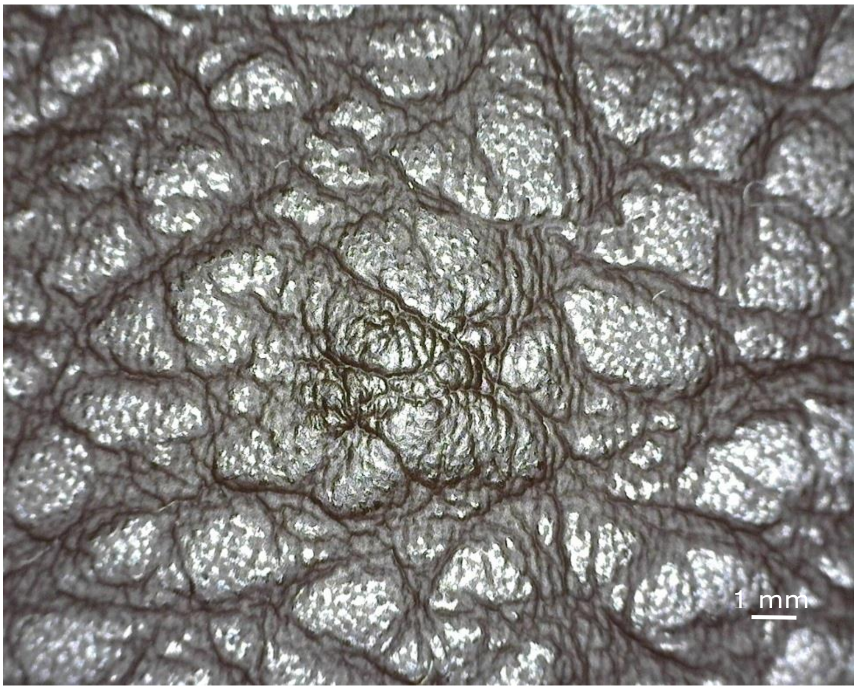


Figure A10.23 The first sample of PU covered fabric after 100 rubs seen through a microscope

Figure A10.24 The first sample of PU covered fabric after 900 rubs

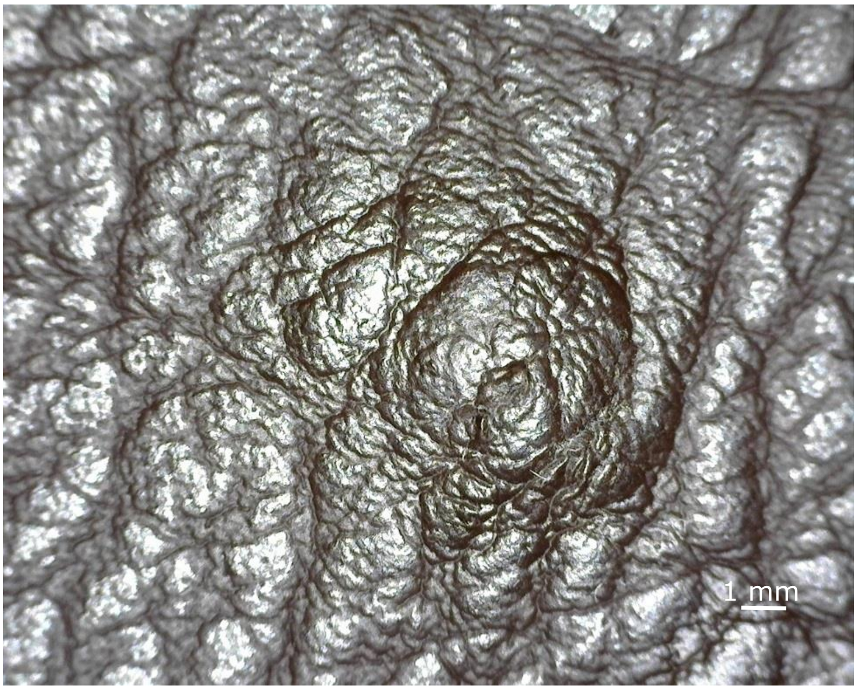


Figure A10.25 The first sample of PU covered fabric after 900 rubs seen through a microscope

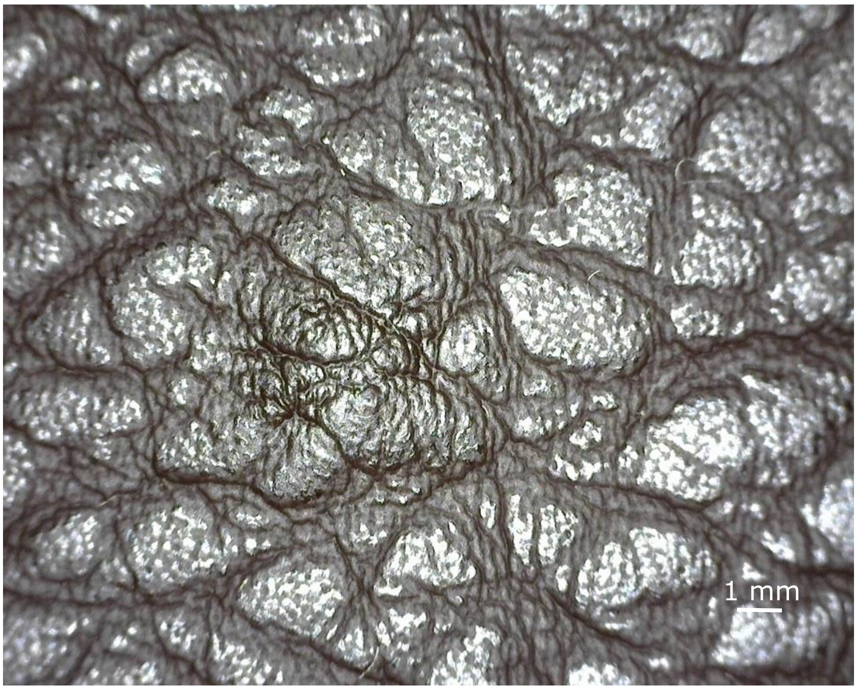


Figure A10.26 The second sample of PU covered fabric after 100 rubs seen through a microscope

Figure A10.27 The second sample of PU covered fabric after 800 rubs seen through a microscope

Appendix 11 Bag patterns

Design “Summer field” has the main part made of black Piñatex® material with embroidered details on the sides. The outer centre part and flap are made of cork material. The flap has an engraved symmetric design with cornflower and poppy blossoms and wheat straws.

Table A11.1 List of patterns for bag "Summer field"

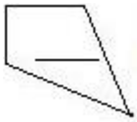
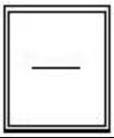
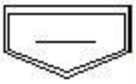
No.	**Piece image**	**Piece name**	**Piece description**	**Single pieces**	**Mirrored pairs**	**Material**
1.		Main piece	Outer front and back detail	1	-	Piñatex® material
2.		Flap	Outer and inner flap details	2	-	Cork material
3.		Centre piece	Decorative detail located in the middle of the main piece surface	1	-	Cork material
4.		Main lining	Lining detail of the main detail	1	-	Lining material

Design “Poppy” has the main part made of cork material with engraved details on the sides. The outer centre part and flap are made of black Piñatex® material. The flap has an embroidered poppy flower in the centre and two laser-cut cork details on the sides as an additional layer.

Table A11.2 Details for bag "Poppy"

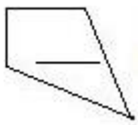
No.	**Piece image**	**Piece name**	**Piece description**	**Single pieces**	**Mirrored pairs**	**Material**
1.		Main piece	Outer front and back detail	1	-	Cork material
2.		Flap	Outer flap detail	1	-	Piñatex® material
3.		Centre piece	Decorative detail located in the middle of the main piece surface	1	-	Piñatex® material

Table A11.2 Details for bag "Poppy"

No.	Piece image	Piece name	Piece description	Single pieces	Mirrored pairs	Material
4.		Flap detail	Decorative detail on the flap	-	1	Cork material
5.		Main lining	Lining detail of the main detail	1	-	Lining material
6.		Flap lining	Lining detail of the flap	1	-	Lining material

Design “Poppy” has the main part made of cork material with engraved details on the sides. The outer centre part and flap are made of black Piñatex® material. The flap has an embroidered poppy flower in the centre and two laser-cut cork details on the sides as an additional layer.

Table A11.3 Details for bag "Ethno"

No.	Piece image	Piece name	Piece description	Single pieces	Mirrored pairs	Material
1.		Main piece	Outer front and back detail	1	-	Piñatex® material
2.		Flap	Outer and inner flap details	2	-	Cork material
3.		Centre piece	Decorative detail located in the middle of the main piece surface	1	-	Cork material
4.		Flap detail	Decorative detail on the flap	-	1	Piñatex® material
5.		Main lining	Lining detail of the main detail	1	-	Lining material

Appendix 12 Prototype production technology

Table A12.1 Processing technology of a bag prototype

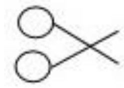
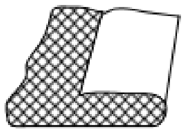
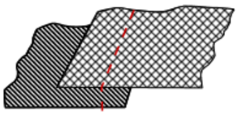
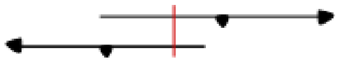
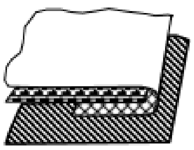
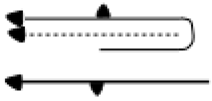
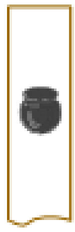
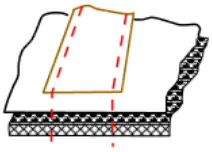
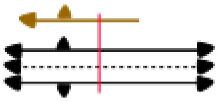
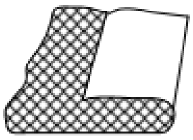
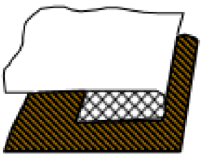
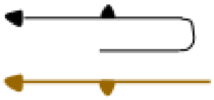
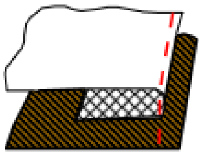
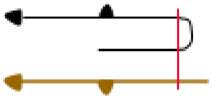
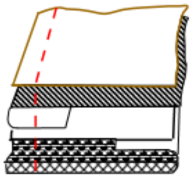
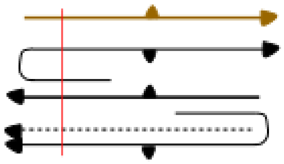
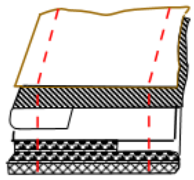
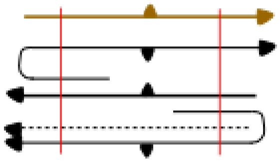
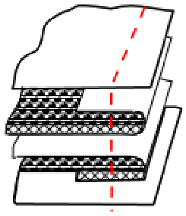
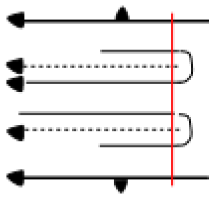
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
1.	Cutting out	By hand			
2.	Ironing back the seam allowances of the lining detail of the bag's main part	Industrial iron	Seam allowance: 1.0 cm Temperature: 110° C		
3.	Sewing bag main detail one shorter side together with a matching side of lining detail	Universal sewing machine	Seam allowance: 1.0 cm Stitch type: 301 Needle R 90 Thread no 50		
4.	Joining the bag main detail and lining using adhesive fabric	Fusing machine	Temperature: 130º C Speed: 3.0 s		
5.	Attaching bag closure buckle bottom part to bag's outer centre detail	Knife			
6.	Attaching the centre detail to the bag's main detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Needle R 90 Thread no 50		
7.	Ironing back the seam allowances of the lining detail of the bag's flap detail	Industrial iron	Seam allowance: 1.0 cm Temperature: 110° C		
8.	Positioning the lining detail on the marked place	By hand			

Table A12.1 Processing technology of a bag prototype

No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
9.	Joining the flap detail with the lining	Universal sewing machine	Seam width: 0.5 cm Stitch type: 301 Needle R 90 Thread no 50		
10.	Attaching the flap detail with the main detail	Universal sewing machine	Seam width: 0.5 cm Stitch type: 301 Needle R 90 Thread no 50		
11.	Top-stitching the combined part of flap detail and the main detail	Universal sewing machine	Seam width: 2.5 cm Stitch type: 301 Needle R 90 Thread no 50		
12.	Joining the bag sides	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Needle R 90 Thread no 50		
13.	Attaching the top part of the buckle	Hammer			
14.	Quality check	By hand			

Appendix 13 Design “Summerfield”

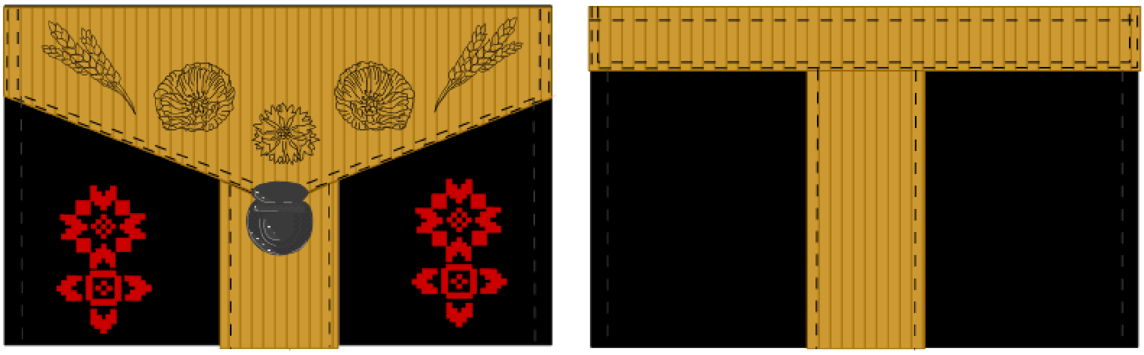


Figure A13.1 Design for "Summerfield"

Table A13.1 Production technology for "Summerfield"

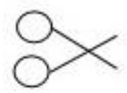
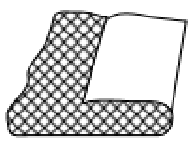
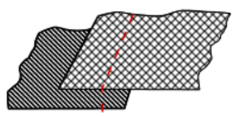
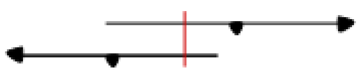
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
1.	Embroidery on Piñatex® material	Embroidery machine	Speed: 500 sps		
2.	Cutting out and engraving cork material details	Laser cutting machine	Engraving: Power: 18% Speed: 80 mm/s Cutting: Power: 23% Speed: 300 mm/s		
3.	Cutting out Piñatex® details	By hand			
4.	Ironing back the seam allowances of the lining detail of the bag’s main part	Industrial iron	Seam allowance: 1.0 cm Temperature: 110° C		
5.	Sewing bag main detail one shorter side together with a matching side of lining detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 4.5 stitches/cm Needle R 90 Thread no 50		

Table A13.1 Production technology for "Summerfield"

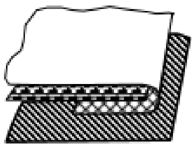
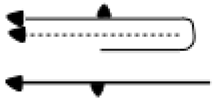
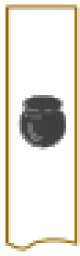
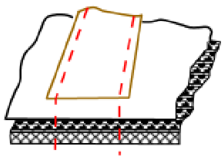
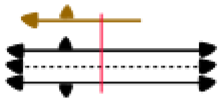
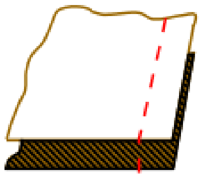
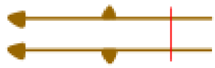
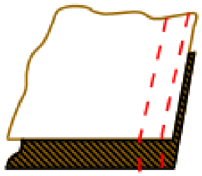
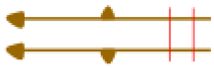
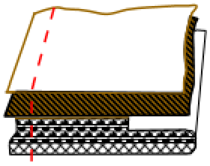
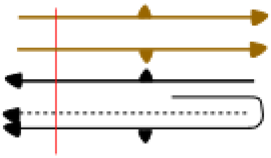
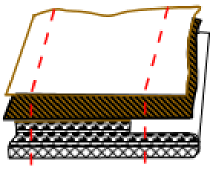
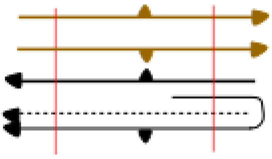
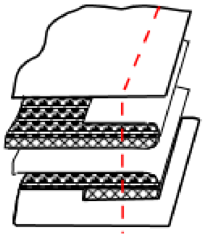
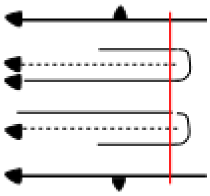
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
6.	Joining the bag main detail and lining using adhesive fabric	Fusing machine	Temperature: 130º C Speed: 3.0 s		
7.	Attaching bag closure buckle bottom part to bag's outer centre detail	By hand			
8.	Attaching the centre detail to the bag's main detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
9.	Joining the flap outer detail and inner detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
10.	Top-stitching the flap detail	Universal sewing machine	Seam allowance: 0.2 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
11.	Attaching the flap detail with the main detail	Universal sewing machine	Seam width: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		

Table A13.1 Production technology for "Summerfield"

No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
12.	Top-stitching the combined part of flap detail and the main detail	Universal sewing machine	Seam width: 2.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
13.	Joining the bag sides	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
14.	Attaching the top part of the buckle	Hammer			
15.	Quality check	By hand			

Appendix 14 Design “Poppy”

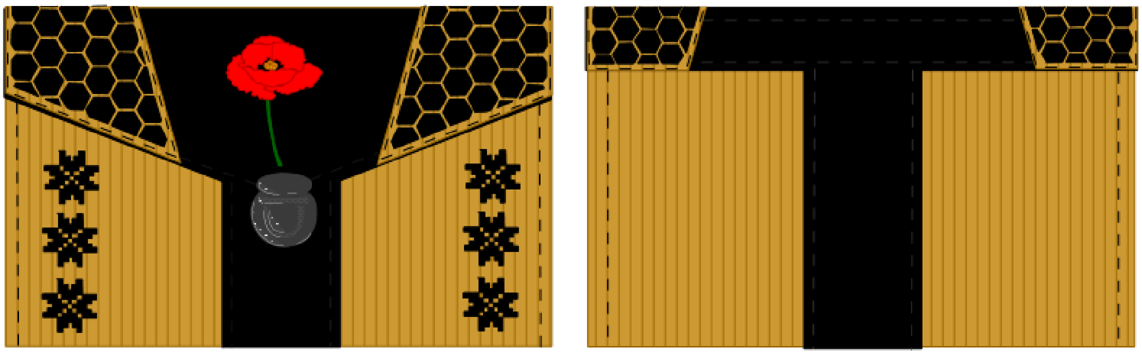


Figure A14.1 Design for "Poppy"

Table A14.1 Production technology for "Poppy"

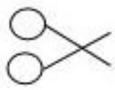
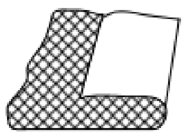
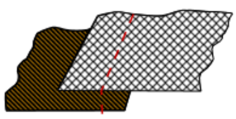
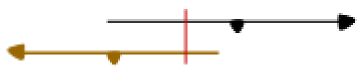
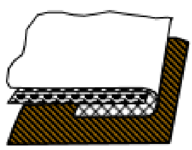
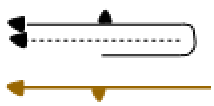
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
1.	Embroidery on Piñatex® material	Embroidery machine	Speed: 500 sps		
2.	Cutting out and engraving cork material details	Laser cutting machine	Engraving: Power: 18% Speed: 80 mm/s Cutting: Power: 23% Speed: 300 mm/s		
3.	Cutting out Piñatex® details	By hand			
4.	Ironing back the seam allowances of the lining detail of the bag’s main part	Industrial iron	Seam allowance: 1.0 cm Temperature: 110° C		
5.	Sewing bag main detail one shorter side together with a matching side of lining detail	Universal sewing machine	Seam allowance: 1.0 cm Stitch type: 301 Stitch density: 4.5 stitches/cm Needle R 90 Thread no 50		
6.	Joining the bag main detail and lining using adhesive fabric	Fusing machine	Temperature: 130° C Speed: 3.5 s		

Table A14.1 Production technology for "Poppy"

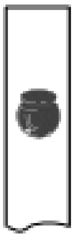
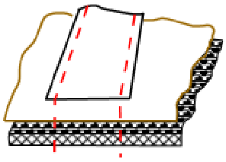
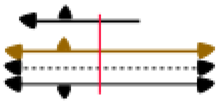
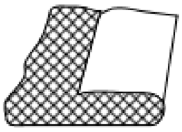
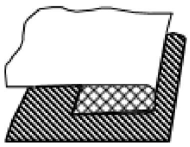
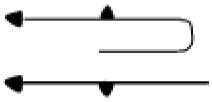
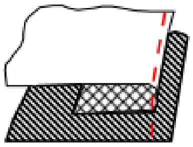
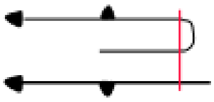
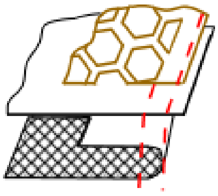
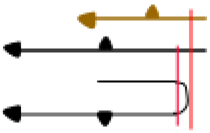
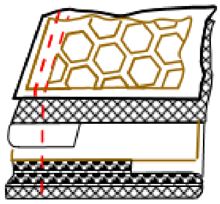
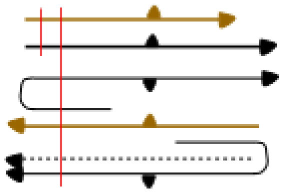
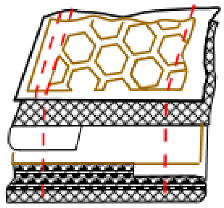
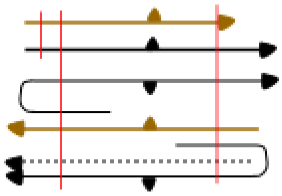
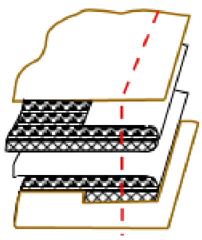
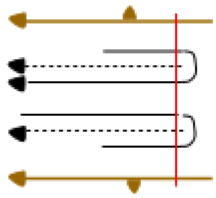
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
7.	Attaching bag closure buckle bottom part to bag's outer centre detail	By hand			
8.	Attaching the centre detail to the bag's main detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
9.	Ironing back the seam allowances of the lining detail of the bag's flap detail	Industrial iron	Seam allowance: 1.0 cm Temperature: 110° C		
10.	Positioning the lining detail on the marked place	By hand			
11.	Joining the flap detail with the lining	Universal sewing machine	Seam width: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
12.	Sewing symmetric decorative details on the flap	Universal sewing machine	Seam allowance: 0.2 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		

Table A14.1 Production technology for "Poppy"

No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
10.	Attaching the flap detail with the main detail	Universal sewing machine	Seam width: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
11.	Top-stitching the combined part of flap detail and the main detail	Universal sewing machine	Seam width: 2.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
12.	Joining the bag sides	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
13.	Attaching the top part of the buckle	Hammer			
14.	Quality check	By hand			

Appendix 15 Design “Ethno”

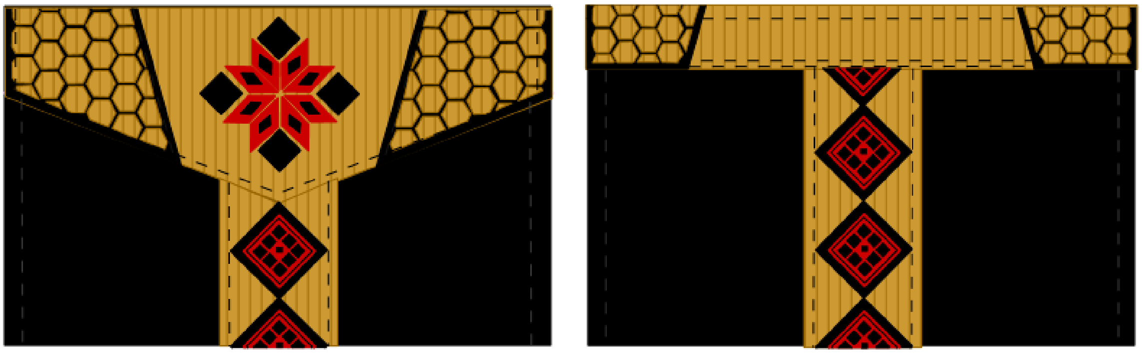


Figure A15.1 Design for "Ethno"

Table A15.1 Production technology for "Ethno"

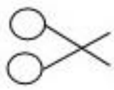
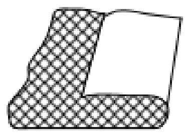
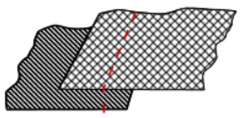
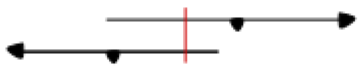
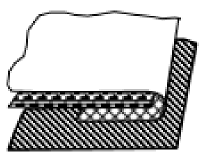
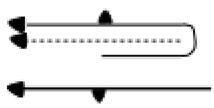
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
1.	Embroidery on cork material	Embroidery machine	Speed: 300 sps		
2.	Printing on cork material	Textile printer	Ink: 5%		
3.	Cutting out cork details	Laser cutting machine	Power: 23% Speed: 300 mm/s		
3.	Cutting out Piñatex® details	By hand			
4.	Ironing back the seam allowances of the lining detail of the bag’s main part	Industrial iron	Seam allowance: 1.0 cm Temperature: 110° C		
5.	Sewing bag main detail one shorter side together with a matching side of lining detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 4.5 stitches/cm Needle R 90 Thread no 50		
6.	Joining the bag main detail and lining using adhesive fabric	Fusing machine	Temperature: 130° C Speed: 3.0 s		

Table A15.1 Production technology for "Ethno"

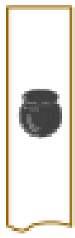
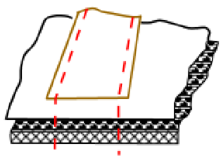
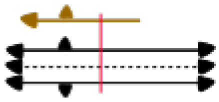
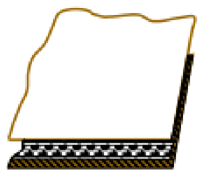
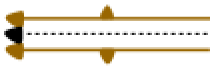
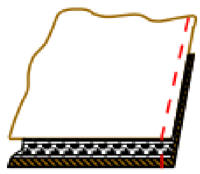
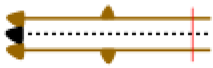
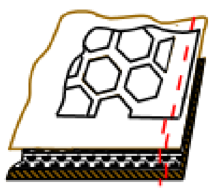
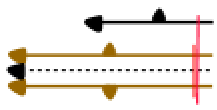
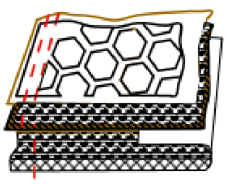
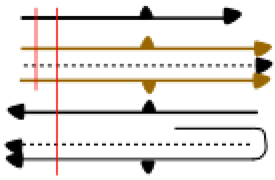
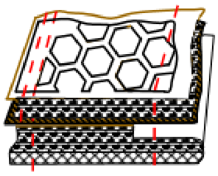
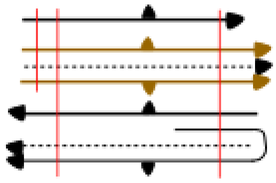
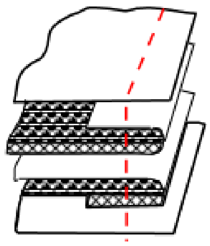
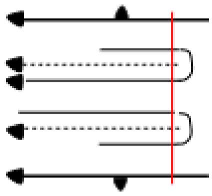
No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
7.	Attaching bag closure buckle bottom part to bag's outer centre detail	By hand			
8.	Attaching the centre detail to the bag's main detail	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
9.	Joining the flap outer detail and inner detail with adhesive fabric	Fusing machine	Temperature: 130º C Speed: 3.5 s		
10.	Top-stitching the flap detail	Universal sewing machine	Seam allowance: 0.2 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
11.	Sewing symmetric decorative details on the flap	Universal sewing machine	Seam allowance: 0.2 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
12.	Attaching the flap detail with the main detail	Universal sewing machine	Seam width: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		

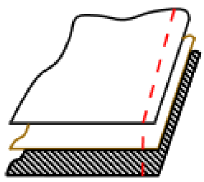
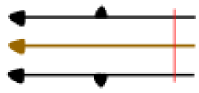
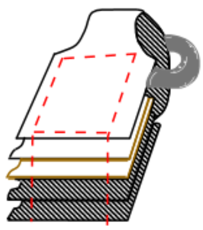
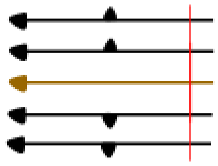
Table A15.1 Production technology for "Ethno"

No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
13.	Top-stitching the combined part of flap detail and the main detail	Universal sewing machine	Seam width: 2.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
14.	Joining the bag sides	Universal sewing machine	Seam allowance: 0.5 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
15.	Attaching the top part of the buckle	Hammer			
16.	Quality check	By hand			

Appendix 16 Bag strap Style 1

Figure A16.1 Design for bag strap Style 1

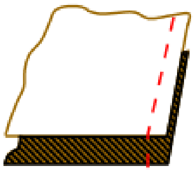
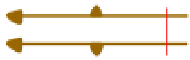
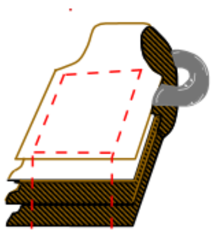
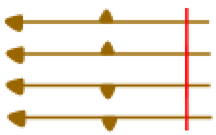
Table A16.1 Production technology for bag strap Style 1

No	**Description of the operation**	**Machine type**	**Technical conditions**	**Material configuration**	**Sectional drawing**
1.	Cutting out Piñatex® details	Laser cutting machine	Power: 50% Speed: 550 mm/s		
2.	Cutting out cork detail	Laser cutting machine	Power: 23% Speed: 300 mm/s		
3.	Sewing together the sides of the strap	Universal sewing machine	Seam allowance: 0.3 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
4.	Attaching snap clip to bag strap by sewing additional detail in the end of the main strap detail	Universal sewing machine	Seam allowance: 0.3 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
5.	Quality check	By hand			

Appendix 17 Bag strap Style 2

Figure A17.1 Design for bag strap Style 2

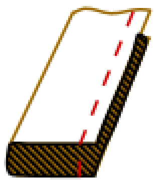
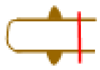
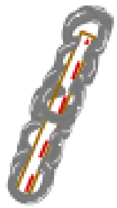
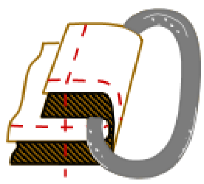
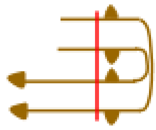
Table A17.1 Production technology for bag strap Style 2

No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
1.	Engraving and cutting out cork details	Laser cutting machine	Engraving: Power: 18% Speed: 80 mm/s Cutting: Power: 23% Speed: 300 mm/s		
2.	Sewing together the sides of the strap	Universal sewing machine	Seam allowance: 0.3 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
3.	Attaching snap clip to bag strap by sewing additional detail in the end of the main strap detail	Universal sewing machine	Seam allowance: 0.3 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
4.	Quality check	By hand			

Appendix 18 Bag strap Style 3

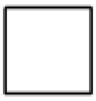
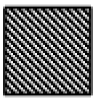
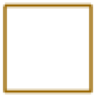
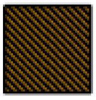
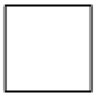
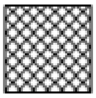
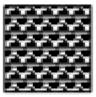
Figure A18.1 Design for bag strap Style 3

Table A18.1 Production technology for bag strap Style 3

No	Description of the operation	Machine type	Technical conditions	Material configuration	Sectional drawing
1.	Cutting out cork details	Laser cutting machine	Power: 23% Speed: 300 mm/s		
2.	Sewing together the sides of the strap	Universal sewing machine	Seam allowance: 0.2 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
3.	Weaving cork strap through the holes of a chain	By hand			
4.	Attaching snap clip to bag strap by sewing the end of the cork strip around the chain	Universal sewing machine	Seam allowance: 0.3 cm Stitch type: 301 Stitch density: 3 stitches/cm Needle R 90 Thread: Silk thread		
5.	Quality check	By hand			

Appendix 19 Explanation of production technology symbols

Table A19.1 Explanations of symbols

Description	Material configuration	Sectional drawing
Piñatex® right-side		
Piñatex® wrong-side		
Cork right-side		
Cork wrong-side		
Lining right-side		
Lining wrong-side		
Adhesive fabric		

Appendix 20 PU covered fabric certificate

Product Certificate

Care instructions:
ISO 3758 DIN EN 23758

Article	08334.000	Description	LEATHER >100.000 MTD
Composition	40%PU/30%VI/30%PL	Washing	30C
Fabric width (cm)	140	Bleaching	
Fabric weight (gr/m2)	320	Ironing	
Customs tariff No.	59039099	Dry cleaning	
Country of origin	CHINA	Drying	

1. Quality standard

		Color Fastness to					
	Shrinkage %	Washing and Water	Dry	Wet	Perspi-ration	Light fastness	Pilling
Test methods acc. to ISO	Washed at 30 degrees	105 C06 A02	105 X12	105 X12	105 D01	105 B02	BS 5811 Standard Photograph
Fabric	-3	4	4	4	4	3/4	4

For non-washable items the requirements for shrinkage and fastness to washing are not demanded. All other requirements are valid.

2. AZO-and chemical confirmation

The supplier assures that the material described overleaf doesn't include AZO dye stuffs, which are illegal according to the European Law. Additionally the supplier assures that the delivered material is free of harmful substance, e.g. allergic dye stuffs and/or other substances in the meaning of 30 LBMG (Consumer Product Degree). The ph-value must be in the range of 4.0-7.5.

3. This declaration is valid for all further shipments of these products dispatched from:

01-01-2019 to 31-12-2019

The fabric must be conform to the given material requirements and EU-instructions and will be herewith confirmed:

Date:

Signature: