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

DEVELOPMENT OF THE REED DRINKING STRAWS WITH DIFFERENT NATURAL FINISHING MATERIALS

PILLIROOST JOOGIKÕRTE TOOTEARENDUS ERINEVATE NATURAALSETE VIIMISTLUSMATERJALIDEGA

MASTER THESIS

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Tallinn, 2020

AUTHOR’S DECLARATION

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

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Thesis is in accordance with terms and requirements

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Accepted for defence

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THESIS TASK

Student: Merike Aro, 182538KVEM

Study programme, KVEM12/18, Technology of Wood, Plastic and Textiles

Main speciality: Wood technology

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Thesis topic:

(in English) Development of the reed drinking straws with different natural finishing materials

(in Estonian) Pilliroost joogikõrte tootearendus erinevate naturaalsete viimistlusmaterjalidega

Thesis main objectives:

1. Determine how the pectins can be removed from the reed straw surface coating
2. Determine what natural finishing materials fasten on the reed straw surface
3. Determine the durability of the natural finishing materials on reed straw surface

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Review previous research on topic	Feb 2019
2.	Presentation of literature finds	March 2019
3.	Collection of essential materials, preparation of the samples	April 2019
4.	Pre-treatment of the samples, testing of the samples	May 2019
5.	Presentation of final report in project 1	May 2019
6.	Testing the samples with airbrush	Sept. 2019
7.	Colouring of the laser engraved samples	Oct. 2019
8.	Laser engraving the samples	Nov. 2019
9.	Colouring of the laser engraved samples	Dec. 2019
10.	Presentation of final report in project 2	Jan. 2020
11.	Further testing (drink tests, wash tests) of the samples	April 2020
12.	Analysis of the results	May 2020
13.	Review on thesis	May 2020
14.	Submission	27.05.2020
15.	Thesis defence	4.06.2020

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School of Engineering

DECLARATION

Please restrict access to my master’s thesis “Development of the reed drinking straws with different finishing materials” and don’t publish it in the Digital Collection of TalTech Library as the thesis contains business secrets.

Sincerely

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Date: 20.05.2020

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CONTENTS

PREFACE

The thesis was placed by Sutu OÜ who is the project client of the author. Sutu OÜ is an Estonian company who's main product is making reed drinking straws which is a sustainable and biodegradable product. Sutu OÜ makes the straws in Estonia, Saaremaa.

The aim of this study is to develop reed drinking straws with different finishing materials. The samples were provided by Sutu OÜ. The current study was carried out in TalTech Laboratory of Wood Technology and also Laboratory of Polymers and Textile Technology where the laser engraver machine is located.

I would like to thank my supervisor Heikko Kallakas for his assistance and advice during the project and Tiia Plamus for assisting me with laser engraving machine.

Keywords: reed, drinking straw, natural finishing materials, product design, master thesis

INTRODUCTION

European Parliament has approved a new law to ban throwaway plastic by year 2021. This includes also single-use plastic cutlery and drinking straws. The goal of the new law is to reduce the environmental harm that plastic pollution has done ("European Parliament," 2020).

Common reed (*Pharmagites australis*) is a renewable organic material that is also biodegradable. Raw material comes from moderate reed cutting to keep the reedbeds tidy and this also maintains good nesting conditions for different wild animals and birds. This makes reed straws a very good and sustainable alternative to single-use plastic straws. From the waste of making reed straws, reed fibre composite is being made which means the whole reed branch is being used fully.

However at this moment there is no research on what natural colours will pigment the reed straw to make it more desirable for target markets. The aim of this thesis is to analyse which natural finishing materials are suitable to colour the reed straws to give extra value to the product. Reed straws end target market are people with higher demands for sustainable products. These straws could be used both by private customer or business customer (e.g. restaurants, bars, event caterers). Using reed straws will lower the use of plastic straws. The research objectives are as follows:

1. Determine how the pectins can be removed from the reed straw surface coating
2. Determine what natural finishing materials fasten on the reed straw surface
3. Determine the durability of the natural finishing materials on reed straw surface

These programs were used to complete the final thesis:

1. Adobe Illustrator and Adobe Photoshop for making the straw designs
2. RD Works V8 for making the laser engraver work files

In this thesis chapter one addresses previous researches about different pre-treatment and testing methods of similar natural materials. Chapter two talks about the materials and methods that were used to achieve the master's thesis aim. Chapter three discusses the results of the testing and after that conclusions are made.

1 LITERATURE REVIEW

There is a more growing demand for sustainable and eco-friendly straws as an alternative to plastic straws. It is affected both by new laws and by people who prefer more eco-friendly solutions to one time use plastic products. The environmentally friendly straws are either made out of biomaterials like paper, wheat, rice or reusable materials like glass, stainless steel and food-grade silicone. These alternative straws are predicting a high market growth due to increasing customer awareness ("Transparency Market Research," 2020).

1.1 Common reed (Pharmagites australis)

Common reed (*Pharmagites australis*) is a wetland plant that can measure up to 4 meters in height. It has a very high productivity and world-wide dominance which makes it a cheap raw material (Köbbing, Thevs, & Zerbe, 2013). Figure 1.1 shows common reed in its natural habitat.

Figure 1.1 Common reed ("Matsalu Teejuht," 2020)

Common reed fibres consist of 40 % cellulose, 22 % lignin, 20 % hemicellulose and 3 % wax (Mounir, Namsi, Agriculture, & Majdoub, 2016).

1.2 Pre-treatment

Plants, including common reed, surface has natural protective wax cover that can potentially hinder the colouring process and result in less adhesion between the finishing material and straw surface. Pectin is the main binder in the main wall and lignin is the encrusting substance gluing the fibre cells together (H. M. Wang & Kessler, 2003). Pectin consist of branched polysaccharides (Yu et al., 2012) . There are different techniques to extract pectin and lignin that are researched in the next four sections.

1.2.1 Chemical processing

According to H.M. Wang and R. Postle's research about removing pectin and lignin during chemical processing of hemp, there is no residual pectin in the fibres after the alkaline treatment. In this process an alkaline boiling scheme was designed where as surfactants sodium silicate 4.5 % and sodium lauryl sulphate 0.08% was used. Additional to that four variable parameters were involved: sodium hydroxide, sodium carbonate, sodium sulphite and treatment time. The temperature used was 120°C under 0.2 Mpa pressure and the time was 50 (H. M. Wang & Kessler, 2003). This processing should be modified to be suitable for using in reed straws since sodium silicate and sodium lauryl sulphate are toxic to humans.

1.2.2 Microwave extraction of pectin

There have been different studies that confirm that Microwave-Assisted Extraction (MAE) has positive effect in plant molecule's pectin extraction (Sandarani, 2017). „MAE is a process of using microwave energy to heat solvents in contact with a sample in order to partition analytes from the sample matrix into the solvent" (S. Wang et al., 2007).

1.2.3 Acidic solution extraction

Different studies have shown that acid extraction gives a good pectin yield. Abang Zaidel has developed a method using citric acid as the extraction solvent to yield pectins from potato cell walls. For this the cell wall materials were put into distilled water for a specific time and the solution pH was adjusted with citric acid. The suspensions were centrifuged and the pectin material neutralized with 32 % NaOH. Pectin residue was washed with ethanol with different intensities (Hamidon & Zaidel, 2017).

1.2.4 Steam treatment

Researches have also shown that the surface wax can be removed by steam treatment above 60°C - 70°C. Steam removes some of the pectins on the surface and makes the later treatments easier (Munawar, Umemura, & Kawai, 2008).

There has been a research made on wheat straws for extraction of the pectic polysaccharides. Steam used was 120°C with 2 bar with different time periods: 15, 30, 60, 120, 180 and 300 min (Lawther, Sun, & Banks, 1996).

1.3 Thermal modification

The reed straw in its raw state is more recipient to ageing and also fungi. It has been proved that thermal modification improves the durability of wood, but it can be successfully apply to other ligno-cellulosic materials like reed or bamboo. Thermal modification can change the colour of thermally modified lignocellulose to darker brown and make it more brittle, so therefore the intensity of heat treatment needs to be closely chosen so that the materials original features don't change (Brischke & Hanske, 2016).

1.4 Colouring bamboo

There is a non-scientific colouring test done to colour bamboo in bright colours which had some positive results. In this testing natural Alta dye, Ujala liquid and tumeric powder were used. The test with tumeric powder wasn't successful since tumeric pigment didn't penetrate through the bamboo ("Auroraville Bamboo Centre," 2020).

The process with Alta dye and Ujala liquid was as followed: 5L water was to boil, then 120ml of Alta liquid or 150ml of Ujala liquid was added, boiled for 10 min and then bamboo straws were added into the boiling water. To compare the results, different bamboos were tested – one wet bamboo sampled and one dry bamboo sample. The samples boiled in the water for 140 min. After boiling the samples were washed with cold water and excess paint was removed with damp cloth. The bamboos were left to dry in a dark dry space for 5 days. The Alta dye gave bamboo a nice bright magenta pink finishing. Ujuala dye gave bamboo a deep indigo colour as seen in Figure 1.2. ("Auroraville Bamboo Centre," 2020).

Figure 1.2. Dyeing the bamboo with natural dyes ("Auroraville Bamboo Centre," 2020)

1.5 Laser engraving drinking straws

Laser engraving the straws require using a laser engraving machine with high-quality finish and speed. Alfex laser has developed a conveyor device where it is loaded by hand, but a hopper feed can be used so the operation needs to be attended only once an hour to reload the hopper. Allfex's Lotus Laser can throughput 1285 straws per hour, but depending on the designs size the quantities can vary ("Alfexlaser," 2018).

Figure 1.3 Laser engraving bamboo straws ("Alfexlaser," 2018)

1.6 Competitors

Reed drinking straws have a few direct competitors where the most similar are bamboo straws. Bamboo straw is also reusable and the straw surface can be laser engraved. Wheat straws, rice straws and paper straws are also natural products, but these can’t be reused since they are thinner materials which makes it weaker than reed or bamboo.

Glass straw, stainless steel straw and silicone straw are indirect competitors since they are not from biodegradable materials, but they are reusable. Prices are also much higher, where one glass straw can cost 5 euros (“Slow,” 2020).

Sutu OÜ-s reed straw package with 16cm straws (10 pcs) costs 8.9 euros on their e-shop, where the package also includes a small brush to clean the straws inside (“Sutu Straws,” 2020). This makes the price of one 16cm straw approximately 0.89 euros. The price for one bamboo straw is approximately 1.50 euros which makes it half as expensive.

The cheapest from the competitors are biodegradable single-time use wheat, rice and paper straws, where the prices vary from 0.044 euros to 0.14 euros per straw. Competitors prices are seen in Table 1.1 in ascending order. Most expensive are reusable straws made from glass, stainless steel and silicone, where the highest price is 5 euros for a 25 cm glass straw.

Table 1.1 Competitors

Material	Reusable	Bio-degradable	Price per package (€)	Price per straw (€)	References
Paper straw 20 cm (100 pcs)	No	Yes	2.7	0.027	(“Pakendikeskus,” 2020)
Rice straws (min order 10 000 pcs)	No	Yes	-	~0.04	(“Nanjing Master Packaging Co,” 2020)
Wheat straw 15 cm (500 pcs)	No	Yes	22.2	~0.044	(“Straw by Straw,” 2020)
Wheat straw 13 cm (100 pcs)	No	Yes	7.36	~0.074	(“HAY! Straws,” 2020)
Paper straw 20 cm (500 pcs)	No	Yes	59.99	0.12	(“Greenest,” 2020)
Rice straw 22 cm (85 pcs)	No	Yes	11.99	~0.14	(“ZotiYuri B.V.,” 2020)
Reed straw 15 cm (10 pcs); Cleaning brush included	Yes	Yes	6.5	~0.65	(“Suckõrs,” 2020)

Material	Reusable	Bio-degradable	Price per package (€)	Price per straw (€)	References
Silicone straw 25 cm (6 pcs); Cleaning brush included	Yes	No	6.9	~1.15	("Amazon," 2020a)
Bamboo straw, non-engraved (10 pcs)	Yes	Yes	11.50	~1.50	("Jungle Straws," 2020)
Bamboo straw, non-engraved (6 pcs); Cleaning brush included	Yes	Yes	9.2	~1.53	("Bambu," 2020)
Silicone straw 23 cm (4 pcs)	Yes	No	10.11	~2.50	("Amazon," 2020b)
Stainless steel straw 21 cm (4 pcs) + cleaning brush	Yes	No	10.15	~2.53	("Elamise Kergus," 2020)
Glass straw 20 cm (1 pcs)	Yes	No	3.5	3.50	("Rohepakend," 2020)
Stainless steel straw (2 pcs); Cleaning brush included	Yes	No	7.45	~3.725	("Apollo," 2020)
Glass straw 25 cm (1 pcs)	Yes	No	5	5	("Slow," 2020)

2 MATERIALS AND METHODS

Here are introduced the materials and methods that were used in practical tests. The reed drinking straws were made out of common reed (*Pharmagites australis*).

2.1 Materials

The reed straws and branches were supplied by Sutu OÜ. The straw dimensions varied from 6 to 9 mm and lengths from 16 cm to 20 cm. The ready cut straws were already mechanically cleaned and thermally processed. The branches, that were cut to size at TalTech Laboratory of Wood Technology, were in their raw state without any treatment, so they required cutting using an electrical plate cutter.

2.2 Development

The requirements for reed drinking straws are that they should be usable in different soft drinks and also in alcoholic beverages. The natural finishing material on the straws shouldn't wear off while in the drink. The straw should be reusable for at least 3 times. The end price of the product shouldn't be much higher than the price for reed straws without a finish. The requirements are seen in Table 2.1.

Table 2.1 Requirements for reed straw development

Features	Required	Recommended
Functions		
Could be used for drinking purpose	Yes	
Could be used for both hot and cold drinks	Yes	
Low price	Yes	
Commercial appearance	Yes	
Technical aspects		
Colour on the straw shouldn't wear off in the drink	Yes	
Drinking straw should be washable		Yes
Vegan-friendly		Yes
BPA-free	Yes	

Features	Required	Recommended
100% biodegradable with the finishing material	Yes	
Handling		
Easy to handle		Yes
Instructions manual and cleaning brush inside the package	Yes	
Low need for maintenance	Yes	

2.3 Design

Design raises the value of the product. Three different collections are presented that are made for laser engraving the straws that can be later coloured with natural finishes. When making the designs, different aspect from nature were taken into account – e.g. shape, texture and colour. These three collections can be sold either separately or they are also suitable to be mixed. First the ideas were sketched on a paper after which the collections were developed (Figure 2.1).

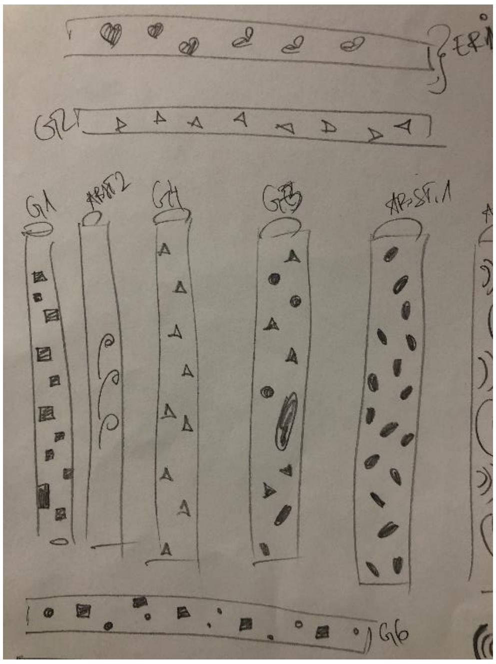


Figure 2.1 Sketching the designs

The designs were made using Adobe Photoshop and Adobe Illustrator programs. The work files for the laser engraving machine were done with RD Works V8 that is compatible with the engraving machine in the Laboratory of Polymers and Textile Technology.

Straw designs were made on a 16cm long straws. In making the designs it is taken into consideration that the pattern doesn't go up to the straw end and ends about 2 cm before. In this way the coloured part of the straw doesn't go into the persons mouth while drinking.

2.3.1 Geometry collection

The geometry collection (Figure 2.2) has nine different designs that are derived from geometric shapes. G1 pattern consist of different size rectangles, G2 different size triangles, G3 has a mix of triangles and circle shapes, G4 has diamond shape, G5 has a mix of rectangles and circles, G6 has different size half-circles, G7 has full circles and half-circles, G8 has rectangles and triangles and G9 has hexagons on it.

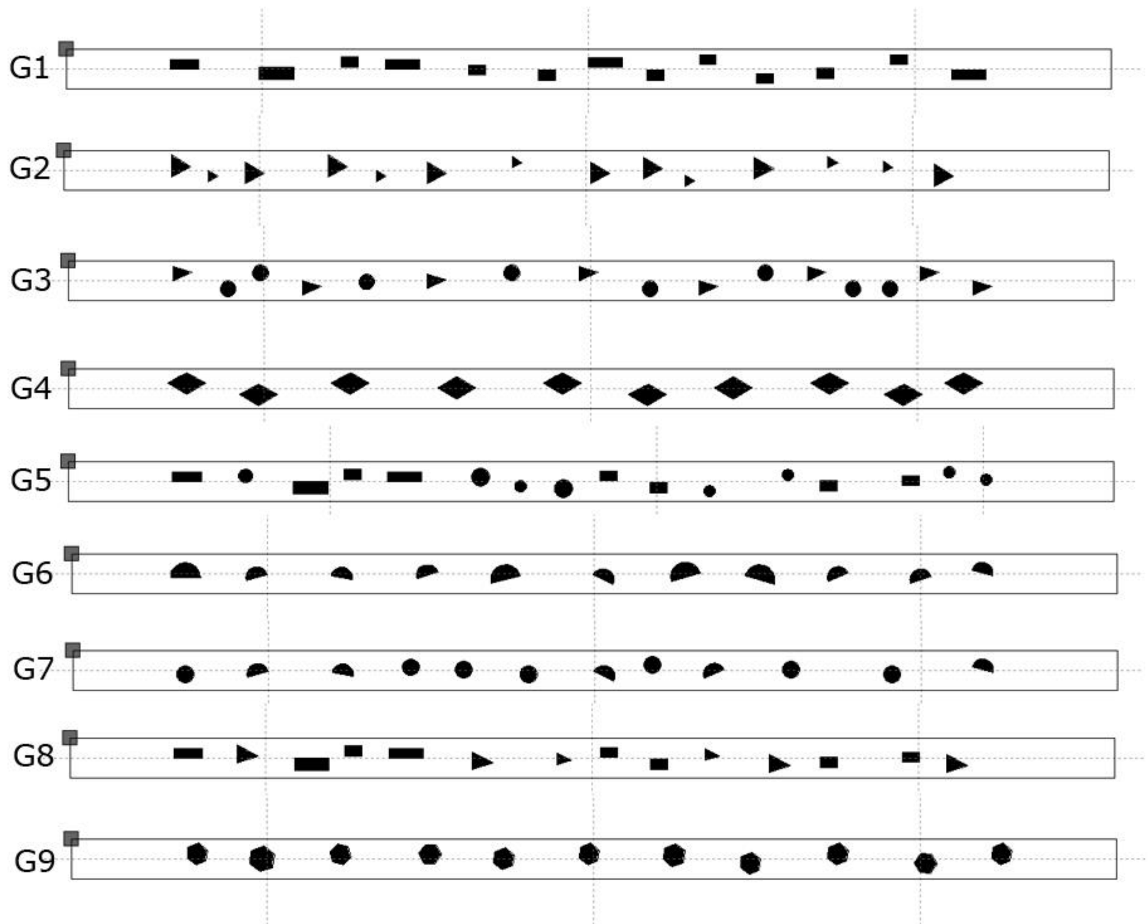


Figure 2.2 Geometry collection

2.3.2 Abstract collection

Abstract collection (Figure 2.3) was put together due to the fact that abstract patterns are in style for several years already in all kinds of different industries (e.g. in textile design, in graphic design).

The abstract collection has seven different designs where the patterns are derived from nature and geometric shapes. For example there are oval shapes that imitates spruce cone, a shape of a single drop that imitates a real drop of rain in a simplified form. There are also different curved and arched forms that are also derived from nature – from trees and leaves.

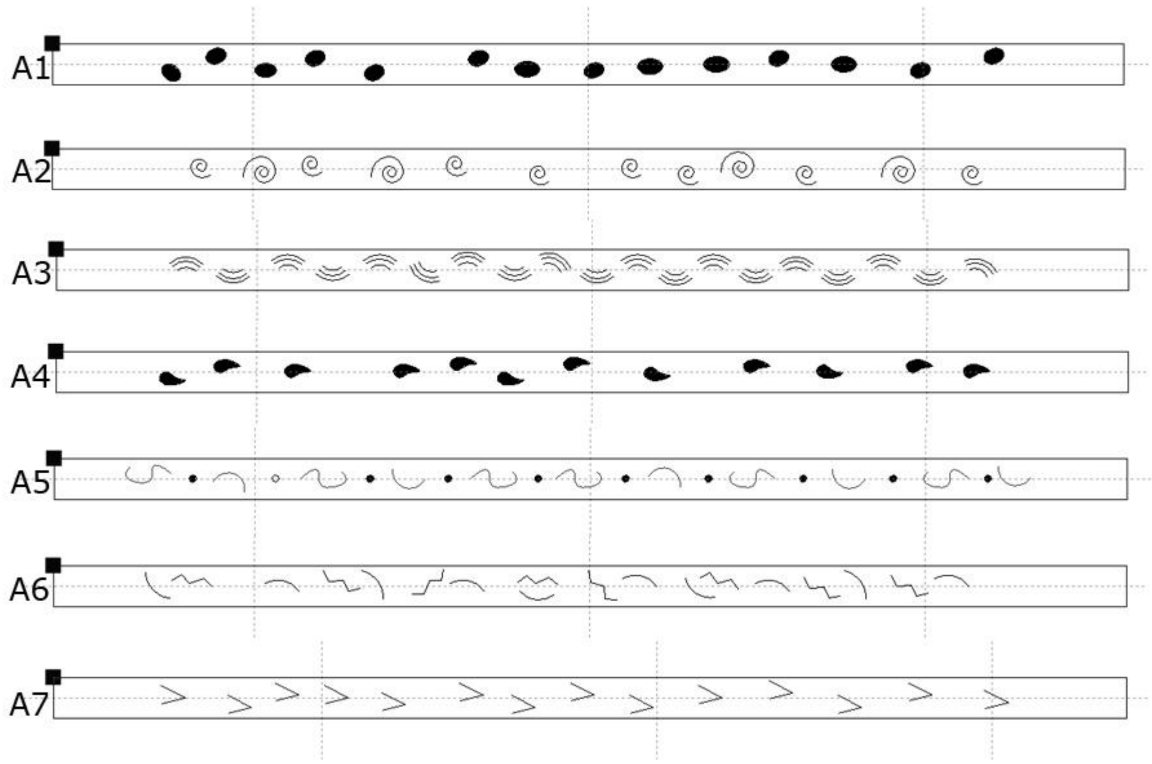


Figure 2.3. Abstract collection

2.3.3 Special collection

The special collection (Figure 2.4) is the smallest collection and it can be used in special occasions – e.g. S1 design that imitates a simplified fir tree and S2 design that is similar to snowflakes can be used according to the season at winter time during the Christmas. S3 design imitates stars and S4 design has different size hearts on it.

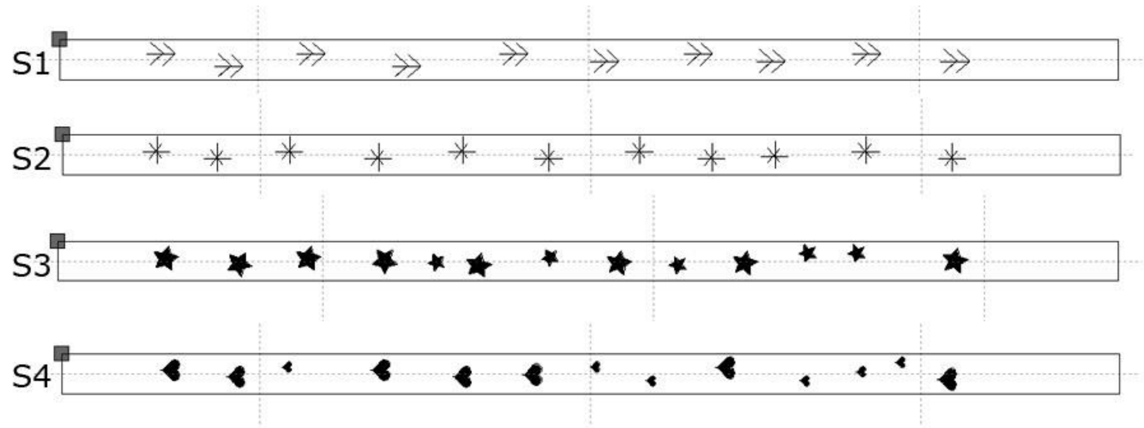


Figure 2.4. Special collection

2.4 Natural food colours

When developing the reed straw design, natural food colours are required that are suitable for food industry. There is a standard ISO 22000:2018 about Food safety management systems – Requirements for any organization in the food chain that needs to be followed to provide safe foods and products. The main food colours that were used were from company PME Trade. Also one pink paste colour from Sugarflair.

Some of the ingredients of both Sugarflair and PME liquid colours might be animal derived and are not suitable for vegans. Unfortunately no confirming information was received from the company and it should be assumed that they are animal derived ("The Elated Vegan," 2020).

Table 2.2 Natural food colours

Colour	Ingredients	Vegan/not vegan	References
PME Black	Carbon black E153	Possibly animal derived	("PME Trade," 2020a)
	Glycerol E422	Possibly animal derived	
PME Orange	Acidity Regulator E330	Vegan	("PME Trade," 2020b)
	Antioxidant Alphatocopherol E307	Vegan	
	Colour Cohineal E123	Vegan	
	Emulisifier polysorbate E433	Possibly animal derived	

Colour	Ingredients	Vegan/not vegan	References
	Humectant Glycerine E422	Possibly animal derived	
PME Moss Green	Colour Sodium copper E141	Vegan	("PME Trade," 2020c)
	Humectant Glycerine E422	Possibly animal derived	
	Riboflavin E101	Vegan	
PME Juniper Green	Colour Sodium copper E141	Vegan	("PME Trade," 2020d)
	Humectant Glycerine E422	Possibly animal derived	
	Riboflavin E101	Vegan	
Sugarflair Pink	Glycerol E422	Possibly animal derived	("Suhkrukunst," 2020)
	Propylen glycol E1520	Vegan	
	Anti-caking agent E551	Vegan	
	Food pigment E129	Vegan	

2.5 Testing

Since there are no standard methods for colouring and pre-treating reed straws then the tests were done on the basis of information that was found in the Literature review about similar materials testing.

For colouring the straws different methods were used. The methods were different depending if the specimens were full straws or laser engraved straws. For colouring full straws there were two main methods as seen in Figure 2.5. In the first method the straws were first pre-treated and only after that the straws were coloured and oven dried. With all the methods for oven drying a Gallenkamp Hot Box Oven with Fan Size 1 was used. In the second method the straws were coloured without any pre-treatment and then oven dried.

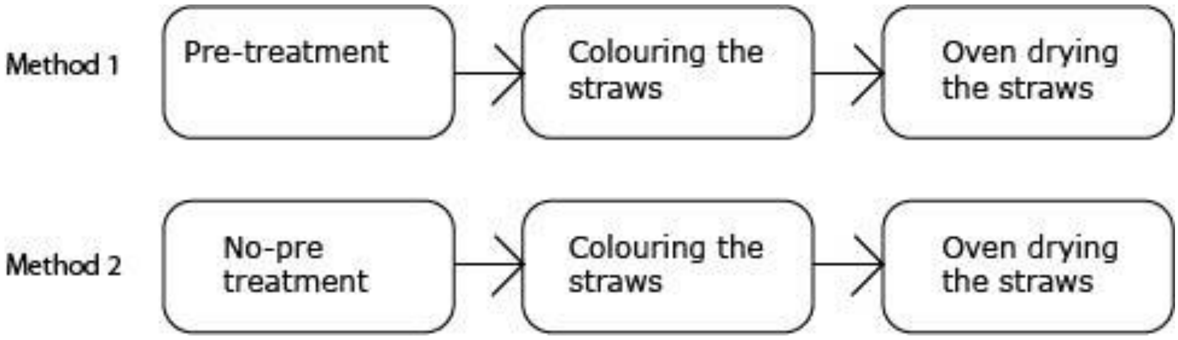


Figure 2.5 Methods for colouring full straws

For testing the laser engraved straws fist the straws had to be laser engraved with a laser engraving machine. In the first method the straws were fist laser engraved, then the engraved parts were coloured with a small brush. After that the straws were oven dried and if the results were satisfying then the durability testing was done on the straws. The second method included an additional oven drying session before colouring the straws as seen in Figure 2.6.

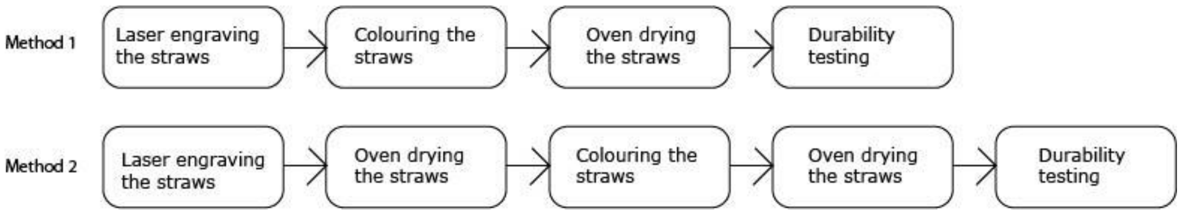


Figure 2.6 Methods for colouring laser engraved straws

2.5.1 Laser engraving

The laser engraving of the straws was done at the Laboratory of Polymers and Textile Technology where the Bodor CO^2 laser engraving and cutting machine is located. For laser engraving a rotating accessorie was supposed to be used, but since it was faulty, there was no possibility to use it and a new one was ordered from China which will take a long time to arrive. Therefore a small device out of wood was made so the straw stays in one place while the machine is working. Seen in Figure 2.7.

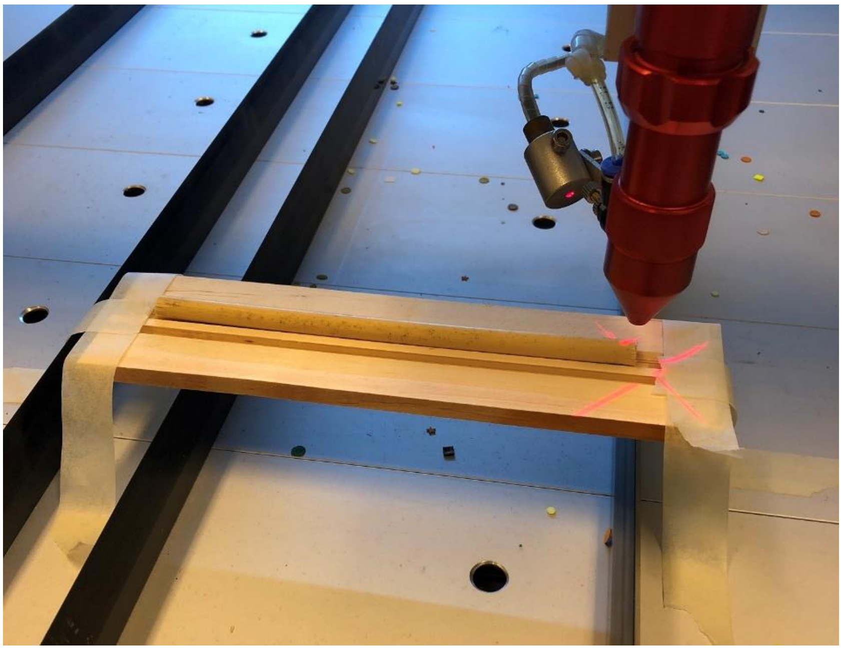


Figure 2.7 Device to hold reed straw in laser engraving machine

For laser engraving scan and cut mode were used. With scan mode the best parameters were 21 W and 400 mm/s. With stronger power the machine cut through the straw and with lower power the pattern was too light on the straw. Scan mode was used with designs where the inner part of the pattern is also engraved. With cut mode the best parameters were 14 W, 650 mm/s. Cut mode was used for thin lines where the laser engraved a nice fine line.

2.5.2 Colouring pre-treated straws

In this chapter different pre-treatments before colouring the straws are explained.

Boiling the specimens before colouring was one of the pre-treatments tested. For this, the samples were put to boiling water for 10 min. After that some of the specimens were left into natural pigments for 24 hours. Some of the specimens were soaked in natural food colours. For natural pigments these pigmentats were used: chopped spinach, matcha tea, crushed black currants, grape juice, boiled beet juice. From food colours Terra Exotique powder food paint and PME liquid food colours were tested. These specimens were later air dried.

Vinegar wasn’t mentioned in the literature review, but since it is a strong acetic acid, it was tested with straws. The straws were put to 30% vinegar solution for 10 min. After that the specimens were put into natural food dyes for 24 hours.

Sodium hydroxide (NaOH) was one of the test subjects to remove cuticle waxes from the straw surface. For this 5 % NaOH solution with different time periods was tested. The specimens were held inside the solution for 5, 10 and 15 min. After that the specimens were oven dried at 130°C. Then the straws were coloured with both powder and liquid food colours.

Citric acid solution (Figure 2.8) with different strengths was tested. Solutions with 5 %, 15 % and 30 % citric acid were used. Both the 5% solution and 15 % solution was tested with different time periods. The specimens were held inside the solution for 5, 10 and 15 min. Pre-treated straws were then oven dried at 130°C and after that soaked in natural food colours.

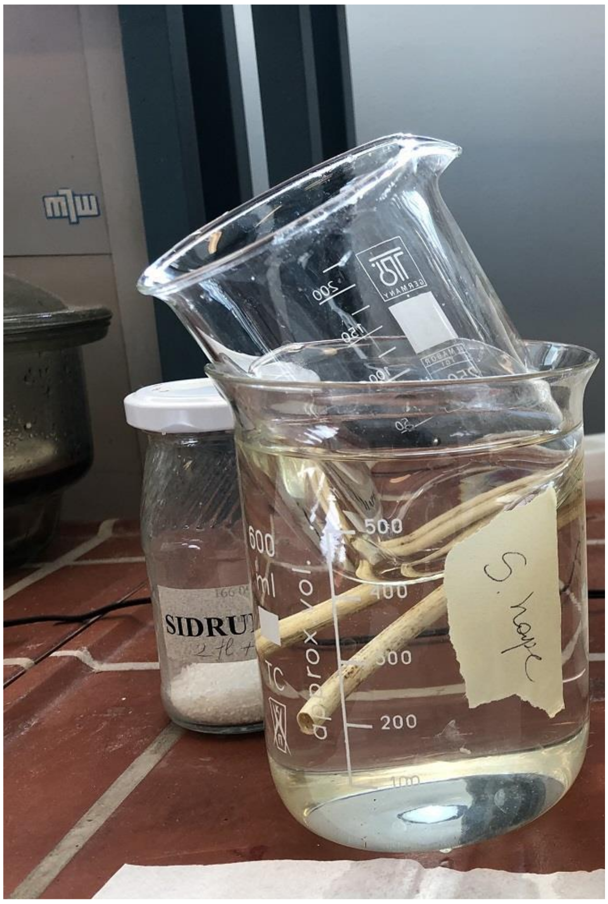


Figure 2.8 Straws inside citric acid solution

Steam pre-treatment was tested with Raute Veneer Drier (Figure 2.9) that is located in the Wood Building. In the fist testing full length straws were put into the drier for 10 min with temperature 155°C, steam 418 g/kg. After that the straws were cut to smaller specimens and soaked in food colours – both powder and liquid colour.

Second time a higher temperature was tested – the specimens were put to the Veneer Drier for 10 min at temperature 210°C. First specimens were held inside the drier with steam, later some specimens were treated without steam to see if there would be a difference.

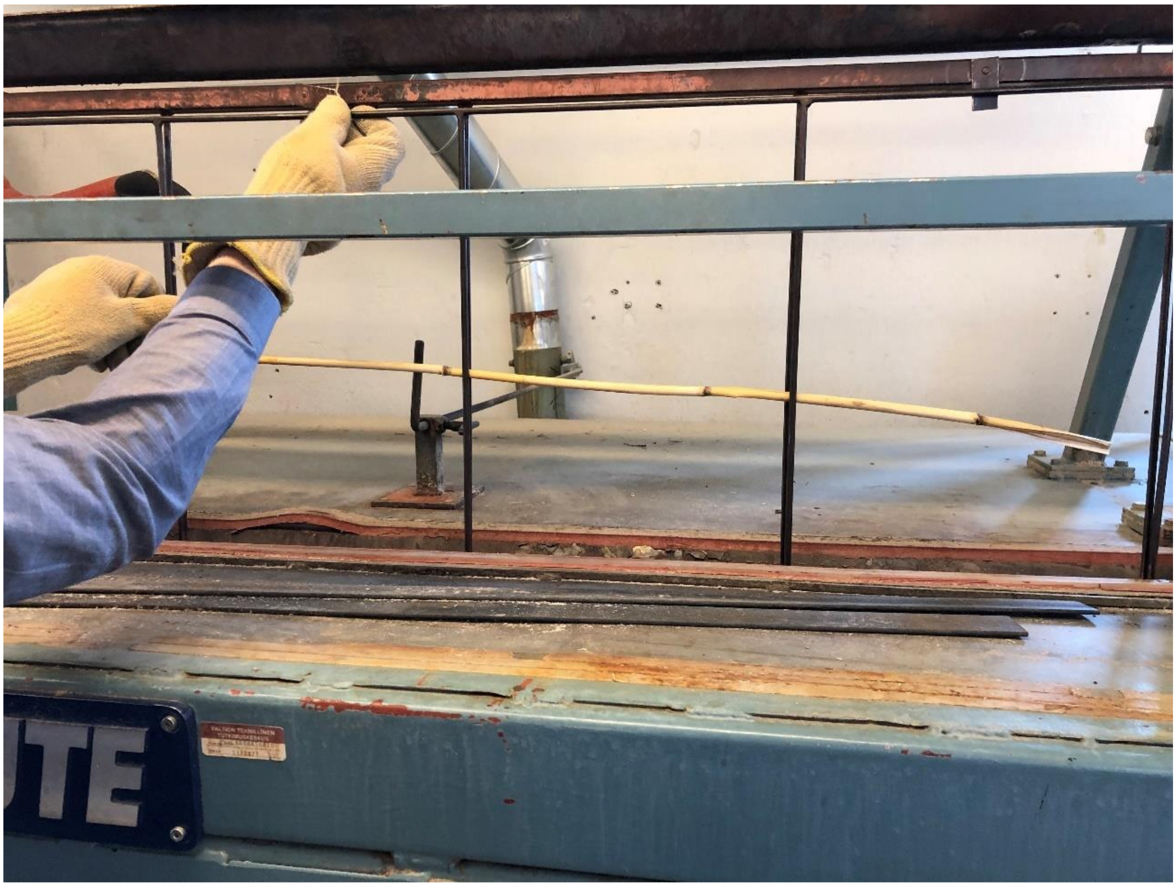


Figure 2.9 Reed straw in Raute veneer dryer

For microwave oven pre-treatment a regular food microwave was used. The straw specimens were first soaked in water to give them some moisture that can evaporate during the microwave treatment. The specimens were put to the microwave for 1 min at the maximum power. Microwave made the straws dry and hot. Later the specimens were soaked in liquid food colour.

Thermal processing was done on some of the laser engraved straws to see if the colour fastens better on thermally modified straws then on straws without pre-treatment. After the treatment, colour was added to the engraved parts by brush. The colour was left on the straw for 30 and 60 min. After that the excess paint was removed with a dry paper napkin and the straws were oven dried at 100°C for 1.5 hours. In one testing the excess paint was left on the straws before put to the oven for 1 hour. Excess paint was removed after oven drying with dry paper napkin.

2.5.3 Colouring straws without pre-treatment

For spraying gun method the paste food colour was too solid and it needed to be diluted with water in 50/50 ration. The food colour then was sprayed to the straws and left to air dry.

Boiling water method was also tested without pre-treatment. The water was set to boil, then food colour or pigment was added to the boiling water and then the straw specimens were put inside the boiling water. The straws boiled inside the water for 30 min. Then some straws were oven dried, some air dried.

Porcelain colour was applied to the straws by brush. Since porcelain colour fastens with heat, the straws were put into the oven for 35 min at 160°C.

Laser engraved straws were mostly painted without any pre-treatment (Figure 2.10). The paint was added to the engraved patterns by a small brush. The paint was left on the straws for different time periods – 30 and 60 min. Later the straws were oven dried. Also different time periods were used – 1 and 1.5 hours at 100°C. One experiment was done also with higher drying temperature. Straws were put into 160°C oven for 20 min.

Figure 2.10 Laser engraved straws after colouring (excess colour on the straws)

2.5.4 Durability test

Durability tests were performed to see how well the coloured straws performed while being in different drinks. For drink tests tap water, 2,5 % milk, Coca-Cola Original, 4,7 % beer, 10 % ethanol solution and 20 % ethanol solution were used (seen in Figure 2.11).

Drink tests were performed 5 times with 1 hour intervals. The straws were examined after 15, 30, 45 min and then in an hour. After that the straws were rinsed in hot water with dishwashing liquid Fairy. To imitate regular use as much as possible the straws were oven dried before next drink test started. This drink test was repeated 5 times (in the next 4 times the straws were examined after 60 min not in every 15 min like in the first hour).

Figure 2.11. Durability test

2.5.5 Warehouse test

To see how well the coloured straws withstand more tougher temperatures and to see if they would preserve there without any damage (e.g. fungus) some straws were put to the shed next to the TalTech Laboratory of Wood Technology. One specimen was left to the shed without any cover, the second specimen was left into the shed inside a mini-grip plastic bag. The straws were held there for 33 days. According to the onset data logger HOBO that was located in the shed the lowest temperature in this period was -4.6°C and the highest 7.2°C. The average temperature was 4.9°C. The lowest relative humidity during this period was 30.1% and the highest 96.6 %. Average relative humidity during this period was 67.2 %. These parameters make the test more extreme than the regular warehouse conditions where the temperature usually is from 14°C and up.

2.5.6 SEM microscopy

For SEM analysis the samples were cut into 1.5 cm long specimens. The specimens were grinded smooth with P400 sandpaper using Buehler AutoMet250 line grinder. The specimens were put into 1.5 cm high form and casted using EpoThin 2 Epoxy Hardener and EpoThin 2 Resin. After the resin had dried, the specimens were gilded to make them electrically conductive for SEM analysis since natural material doesn't conduct electricity. Gilded specimens are seen in Figure 2.12. For gilding Quorum Q150R S rotary pumped coater was used. The analysis itself was done with Zeiss Ultra 55 FEG-SEM (Field emission gun scanning electron microscope). Different magnifications were used – from 28 times to 2000 times.

Figure 2.12 Specimens in resin

2.5.7 Optical microscopy

Optical microscopy was done using a Nikon Eclipse ME600 Inspection Microscope (Figure 2.13). Pictures were taken using a NIS- Elements F imaging software. For cross-section a 4x magnification and for longitudinal section a 10x magnification was used. The samples were first cut to 1.5 – 2 cm size and then the edges were grinded smooth by hand fist with P350 sandpaper and later with a more smooth P1200 sandpaper.

Figure 2.13 Optical microscopy Nikon Eclipse ME600

3 RESULTS AND DISCUSSION

Different practical tests were made to determine what colours and with which treatment fasten on the straw surface. In the first part the practical tests were made on colouring the full straws, in the second part the tests were made on laser engraved straws.

3.1 Laser engraving

In geometry collection only scan mode was used since all the designs had a pattern that was engraved fully. Laser engraved geometry collection is seen in Figure 3.1. In abstract collection both scan and cut modes were used. Scan mode in abstract collection was used only with designs A1 and A4. Abstract collection is seen in Figure 3.2. In special collection designs S1 and S2 were done with cut mode, S3 and S4 in scan mode. Laser engraved special collection is seen in Figure 3.3.

Figure 3.1 Geometry collection

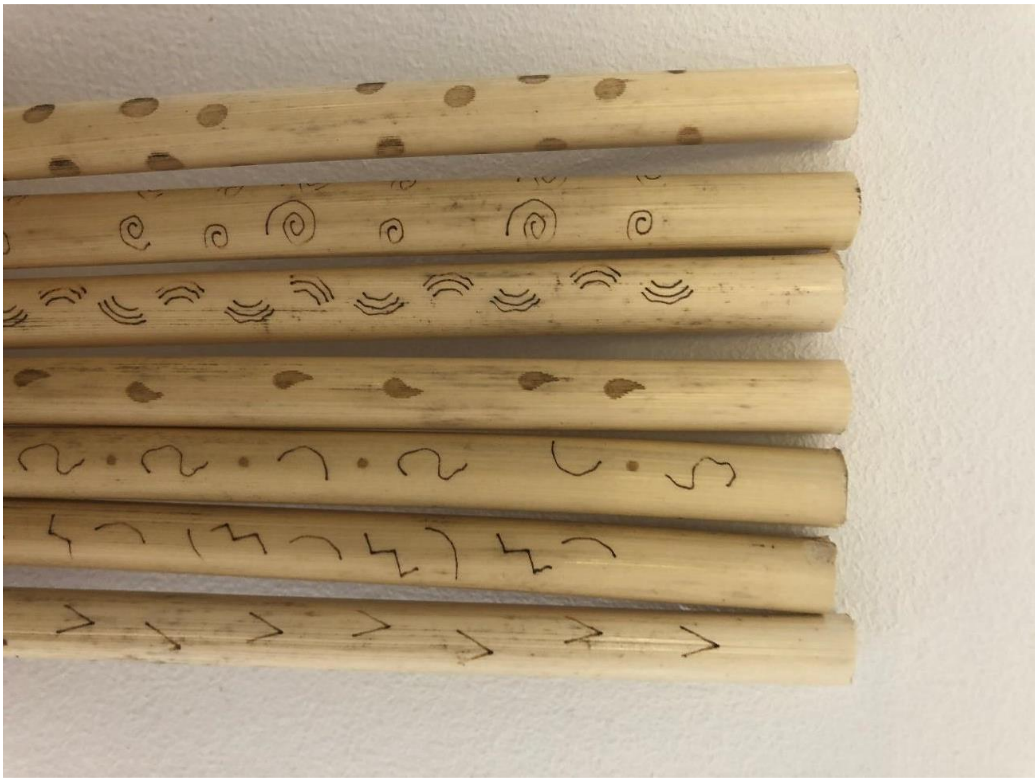


Figure 3.2 Abstract collection

Figure 3.3 Special collection

3.2 Colouring properties of full straws

For colouring full straws different methods were tested. In total 41 test was done, where 6 different pre-treatments were tested as seen in Table 3.1. Seven different natural pigments and three different food colours was used during the testing. Test results of the colouring is seen in Table 3.2.

Table 3.1 Full straws colouring summary

Number of tests	Number of different pre-treatments	Number of different natural pigments used	Number of different food colours used
41	6	7	3

Boiling the straws before colouring didn't give any effect on the colouring properties. Keeping the straws inside blackcurrant gave the best pigment, but still not satisfying result (Figure A.1).

Vinegar pre-treatment didn't have any effect on the straws wax layer. The best outcome was with blackcurrants, but the result wasn't good enough to go further with it (Figure A.2).

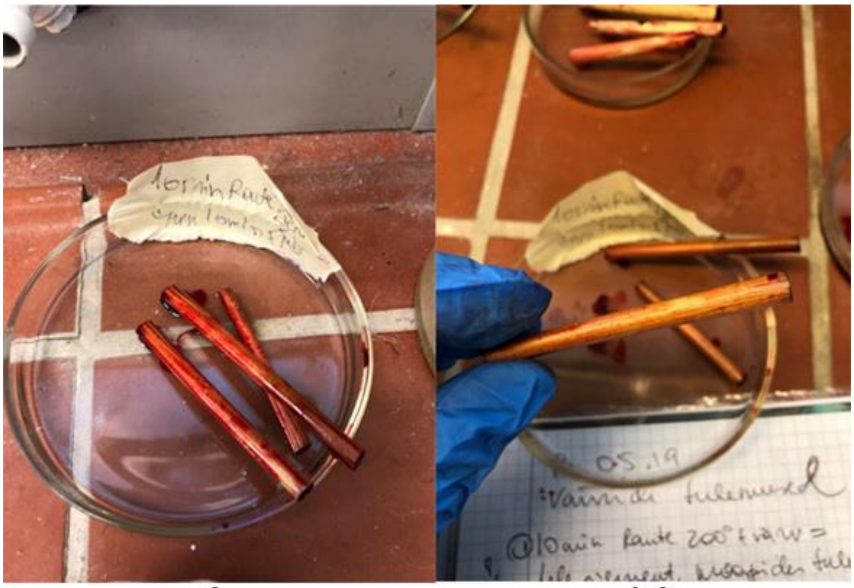
Sodium hydroxide (NaOH) corroded the straws and made them turn yellow already before soaking the straws inside food colour. The colour fastened better on the straws, but since the straws texture was already jaded, the end result wasn't satisfying (Figure A.3).

Citric acid 15 % solution was one of the best results when testing the colouring of the full straws. After the pre-treatment the straws were soaked inside liquid food colour. The colour fastened pretty evenly on the straw surface as seen in Figure 3.4. Unfortunately some of the paint didn't fasten on the straw and still left stains on hands when handling the straws.

a) b)

Figure 3.4 Straws with 15 min 15 % citric acid pre-treatment, later soaked in PME liquid food colour and air dried: (a) straws after colouring with wet paint; (b) straws after the colour has dried

Steam was another testing method that gave somewhat satisfying results to colouring the straws. Results are seen in Figure 3.5.



a) b)

Figure 3.5 Straws in Raute Veneer Drier for 10 min (steam 210°C), then soaked in paint for 10 min: (a) straws after colouring with wet paint; (b) straws after the colour has dried

Microwave oven pre-treatment didn't have any effect on the reed straw surface wax. The colour didn't fasten at all and started wearing off (Figure A.4).

Without pre-treatment straws different colouring methods were used.

The spraying gun technique didn't have a good result. The paint drew into small drops on the straw and didn't air dry even after seven days. Oven drying didn't also help since 60 min treatment in 80°C didn't dry the paint (Figure A.5).

Boiling the straws with colour pigment added to the water, didn't have positive results. PME Black colour left the surface grimy after drying as seen in Figure A.6. Boiling the straws with Juniper Green food colour gave the straws some pigment to them, but the end result didn't look appetising (Figure A.7). Boiling the straws with spirulina powder that has a natural strong pigment, didn't also have any effect on the reed surface colour (Figure A.8).

Porcelain colour covered the straw surface with a thicker layer of paint, but with this result it lost the natural straw look and this was not a desired aim (Figure A.9).

Table 3.2 Colouring properties of the full straw

Pre-treatment to straws	Finishing material	Result
10 min in boiling water	Inside chopped spinach for 24 h	Not satisfying
10 min in boiling water	Inside matcha tea for 24 h	Not satisfying
10 min in boiling water	Inside adjika sauce for 24 h	Not satisfying
10 min in boiling water	Inside crushed black currants for 24 h	Somewhat satisfying
10 min in boiling water	Inside grape juice for 24 h	Not satisfying
10 min in boiling water	Inside boiled beet juice for 24 h	Not satisfying
10 min in boiling water	Inside cherry juice for 24 h	Not satisfying
5 min in boiling water	Soaked in Terra Exotique powder food paint	Not satisfying
5 min in boiling water	Soaked in PME liquid food colour	Not satisfying
10 min in boiling water	Soaked in Terra Exotique powder food paint	Not satisfying
10 min in boiling water	Soaked in PME liquid food colour	Some of the colour fastened to the straw
10 min in 30 % vinegar solution	Inside grape juice for 24 h	Not satisfying
10 min in 30 % vinegar solution	Inside boiled beet juice for 24 h	Not satisfying
10 min in 30 % vinegar solution	Inside cherry juice for 24 h	Not satisfying
10 min in 30 % vinegar solution	Inside crushed black currants for 24 h	Somewhat satisfying

Pre-treatment to straws	Finishing material	Result
5 min in 5 % sodium hydroxide solution (NaOH), oven dried 130°C	Soaked in Terra Exotique powder food paint	NaOH corroded the straw and made it yellow. Food colour didn't fasten
5 min in 5 % sodium hydroxide solution (NaOH), oven dried 130°C	Soaked in PME liquid food colour	NaOH corroded the straw and made it yellow. Food colour didn't fasten
10 mi in 5 % sodium hydroxide solution (NaOH), oven dried 130°C	Soaked in Terra Exotique powder food paint	NaOH corroded the straw and made it yellow. Food colour didn't fasten
10 min in 5 % sodium hydroxide solution (NaOH), oven dried 130°C	Soaked in PME liquid food colour	NaOH corroded the straw and made it yellow. Food colour didn't fasten
15 min in 5 % sodium hydroxide solution (NaOH), oven dried 130°C	Soaked in Terra Exotique powder food paint	NaOH corroded the straw and made it yellow. Food colour didn't fasten
15 min in 5 % sodium hydroxide solution (NaOH), oven dried 130°C	Soaked in PME liquid food colour	Best result with 5% NaOH pre-treatment, but still not good enough
5 min in 5% citric acid, oven dried 130°C	Soaked in Terra Exotique powder food paint	Not satisfying
5 minutes in 5 % citric acid, oven dried 130°C	Soaked in PME liquid food colour	Not satisfying
10 min in 5 % citric acid, oven dried 130°C	Soaked in Terra Exotique powder food paint	Not satisfying
10 min in 5 % citric acid, oven dried 130°C	Soaked in PME liquid food colour	Not satisfying
15 min in 5 % citric acid, oven dried 130°C	Soaked in Terra Exotique powder food paint	Not satisfying
15 min in 5 % citric acid, oven dried 130°C	Soaked in PME liquid food colour	Best result with 5% citric acid pre-treatment, but still not good enough
5 min in 15 % citric acid solution	Soaked in PME liquid food colour for 10 min	Paint fastened to the straw pretty evenly
10 min in 15 % citric acid solution	Soaked in PME liquid food colour for 10 min	Paint fastened to the straw pretty evenly
15 min in 15 % citric acid solution	Soaked in PME liquid food colour for 10 min	Paint fastened to the straw pretty evenly
15 min in 30 % citric acid solution	Coloured with brush PME liquid food colour; Colour on straw for 30 min, oven dry for 30 min at 100°C	Not satisfying, colour was still wet after OD
10 min in Raute veneer dryer (155°C, steam 418 g/kg)	Soaked in Terra Exotique powder food paint	Dryer made the straw brittle, powder colour didn't fasten to the straw
10 min in Raute veneer dryer (155°C, steam 418 g/kg)	Soaked in PME liquid food colour	Some of the colour fastened to the straw

Pre-treatment to straws	Finishing material	Result
10 min in Raute veneer dryer (210°C)	Soaked in PME liquid food colour	Pre-treatment turned the straws darker (brown), after drying the paint was pretty even
1 min in microwave oven with maximum power (straws made wet before treatment)	Soaked in PME liquid food colour	Uneven paint spots on the straw after drying
No pre-treatment	Spraying 50/50 PME white paste/water solution with spray gun, didn't air dry in 7 days; Later oven dried 60 min at 80°C	Uneven paint on the straws even after oven drying
No pre-treatment	Boiling water + 1 tbs PME Black liquid food colour. Boil for 18 min, oven dry for 35 min 160°C	Paint didn't fasten to the straws
No pre-treatment	Boiling water + 1 tbs PME Black liquid food colour. Boil for 18 min, air dry	Paint didn't fasten to the straws
No pre-treatment	Boiling water + 1 tbs PME Juniper Green; Boil for 30 min; Air dry	Straws turned lightly green, but not a very appealing look in general
No pre-treatment	Boiling water + 1 tbs of spirulina powder; Boil for 20 min	No pigment on the straws
No pre-treatment	Porcelan Art porcelain colour; Applied with brush; Oven dried 35 min 160°C	Straws don't look like natural straws after porcelain colour is fastened

3.3 Colouring properties of laser engraved straws

Laser engraved straws were tested with different natural pigments. The straws that were held inside beetroot juice (Figure B.10) and cherry syrup (Figure B.11) for 3 hours didn’t have any effect on the straw surface. Straws that were inside spirulina powder (Figure B.12) left a light green pigment on the parts that were engraved. Results are seen in Table 3.3.

With using the liquid food colours all the results were satisfying. PME Orange gave a nice light yellow/orange tone to the patterns (Figure B.13), PME Moss Green (Figure B.13) made the patterns light green and PME Black made the patterns black. Sugarflair Pink colour made the patterns most sharp and gave the engraved patterns an extra strong pink colour (Figure B.13).

PME Black had satisfying results with all the pre-treatment methods. In Figure 3.6 two of those are shown where (a) are oven dried straws at 160°C where the higher temperature turned the straws darker and (b) where the oven treatment at 100°C dried the straws evenly without tampering the straw's surface colour.

Figure 3.6 Coloured straws: (a) Oven dried at 160°C for 20 min; (b) Oven dried at 100°C for 1.5 h

Table 3.3 Colouring properties of laser engraved straws

Straw design	**Finishing material**	**Drying method**	**Result**
G5	Sugarflair Pink	Air dry	Satisfying
S3	Sugarflair Pink	Air dry	Satisfying
S3	Sugarflair Pink	Oven dry 1 h with 100°C	Very satisfying
Scan 14 W, 400 mm/s	Sugarflair Pink	Air dry	Satisfying
G1 and G3	Inside beetroot juice for 3 h	Air dry	Not satisfying
G3	Inside cherry syrup for 3 h	Air dry	Not satisfying
G3 and G6	Inside spirulina powder with a drop of water for 3 h	Air dry, excess powder removed with water	Some pigment was left on the pattern, but not enough

Straw design	Finishing material	Drying method	Result
G3	30 min in PME Black	Oven dry 20 min with 160°C	Straws turned darker (brown), food colour looks good on the pattern
Mix	30 min in PME Black	Oven dry 1.5 h 100°C	Very satisfying
Mix	1 h in PME Black	Oven dry 1.5 h 100°C	Very satisfying
Mix	30 min in PME Moss Green	Oven dry 1.5 h 100°C	Satisfying
Mix	Oven dry before colour for 1 h at 100°C, then in PME Black for 1 h	Oven dry 1 h 100°C	Very satisfying
Mix	Oven dry before colour for 1 h at 100°C, then in PME Black for 1 h	Oven dry 1.5 h 100°C	Very satisfying
Mix	Oven dry before colour for 1 h at 100°C, then in PME Orange for 1 h	Oven dry 1.5 h 100°C	Satisfying

3.4 Durability properties

Durability properties were tested only on laser engraved straws since only these were with very satisfying results. Test results are seen in Table 3.4. The straws were analysed with visual inspection.

Sugarflair Pink colour gave a satisfying result after colouring test, but unfortunately this colour wear off in the first hour inside drink as seen in Figure 3.7. Therefore this result is not shown in Table 3.4.

Figure 3.7 Laser engraved straws with Sugarflair Pink after 4 hours of durability testing

With PME Black liquid colour all three durability tests gave very good results. The colour didn’t wear off after 5 hours of different drink tests. First the straws that were coloured and then oven dried for 1.5 hours at 100°C, secondly straws that were fist thermally modified and then coloured and oven dried for 1.5 hours at 100°C (Figure C.14) and thirdly straws that were fist thermally modified and then put to the oven with excess colour (Figure C.15) – all of these straws had a very satisfying results after durability testing. The results of oven dried after the excess colour was removed with a paper napkin for 1.5 h at 100°C are seen in Figure 3.8.

PME Orange had different results in different drinks. The colour was still fastened on the straws 100 % after 5 hours with tap water, Coca-Cola and beer test. Inside milk 50 % of the colour wear off in the first hour. After 4 hours most of the colour was off (90 %). Orange colour didn’t also endure to both 10 % and 20 % ethanol solutions – 50 % of the colour wear off in the first hour and after 4th hour 80 % was worn off (Figure C.16).

Straws with PME Moss Green colour were put to extreme conditions. These straws were held inside a water bath at 70°C for 24 hours. After taking the straws out and drying them, all the straws had lost only 30 % of the colour (Figure C.17).

Table 3.4 Durability test properties

	PME Moss Green ((oven dried 1 h 100°C)	PME Black (oven dried 1.5 h 100°C)	PME Black (oven treated before colour1h 100°C, colour oven dried 1.5 h 100°C)	PME Black (oven treated before colour1h 100°C, colour oven dried with excess colour 1.5 h 100°C)	PME Orange (oven dried 1.5 h 100°C)
Tap water	30 % of the pigment still on after 24h in 70°C water bath	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours
Milk 2.5 %	30 % of the pigment still on after 24h in 70°C water bath	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours
Coca-Cola	30 % of the pigment still on after 24h in 70°C water bath	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours
Beer 4.7 %	30 % of the pigment still on after 24h in 70°C water bath	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours
10% ethanol solution	30 % of the pigment still on after 24h in 70°C water bath	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours	50 % of the pigment off after 1h, 80% off after 4h
20 % ethanol solution	30 % of the pigment still on after 24h in 70°C water bath	Colour still fastened after 5 hours	Colour still fastened after 5 hours	Colour still fastened after 5 hours	50 % of the pigment off after 1h, 80% off after 4h

Figure 3.8 Straws with PME Black after 5x1 h drink test and 5x wash test (colour oven dried after the excess colour was removed with a paper napkin for 1.5 h at 100°C)

3.5 Warehouse test properties

The coloured straws were put to more extreme conditions than in a standard warehouse for 33 days where the average temperature was 4.9°C and average relative humidity

67.2 %. The test outcome was positive since there were no visual changes to the straws after the test (Figure D.18).

3.6 SEM properties

With SEM microscopy the reed straw's cross-section was visually analysed to study the morphology of reed fibre. The figures magnifications are in millimeters (mm) and micrometers (µm).

A reed straw without any treatment (Figure 3.9) was compared to a straw that had passed durability testing (Figure 3.10). When comparing the 300x magnification figures it can be seen that the straw without any treatment has a thicker surface layer than the straw that has gone through the durability testing so it can be concluded that the testing has affected the surface wax layer to decrease.

When comparing the straws that were boiled inside water with PME Juniper Green food colour added to it (Figure E.19) with straws without any treatment (Figure 3.9) it can be seen that there is no difference in the outer layer of the reed straw and it can be concluded that the boiling water didn't affect the surface wax layer and the this was the reason food colour wasn't able to fasten on the surface.

Straws that were coloured with Porcelain art porcelain colour had the surface covered with thick paint when comparing to straws without any finishing. The SEM images of straws with porcelain colour are seen in Figure E.20. In 500 times magnification it can be seen that the colour has penetrated through the wax layer and is covering the whole straw surface.

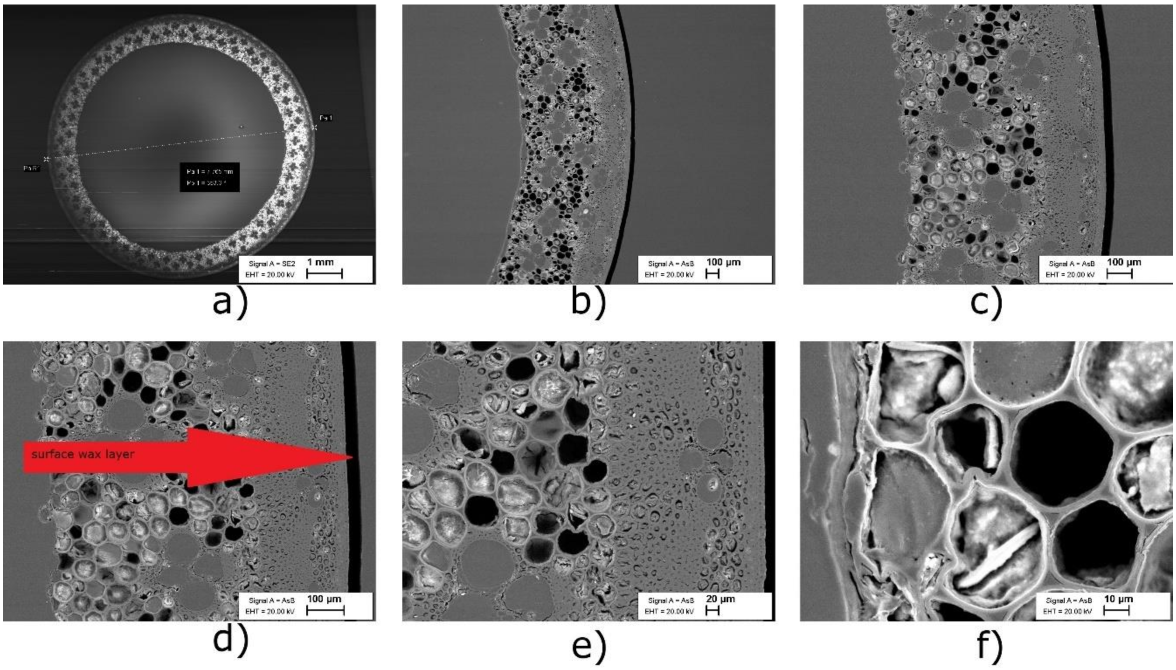


Figure 3.9 Straw without any finish: (a) 28x magnification; (b) 100x magnification; (c) 200x magnification; (d) 300x magnification; (e) 500x magnification; (f) 2000x magnification

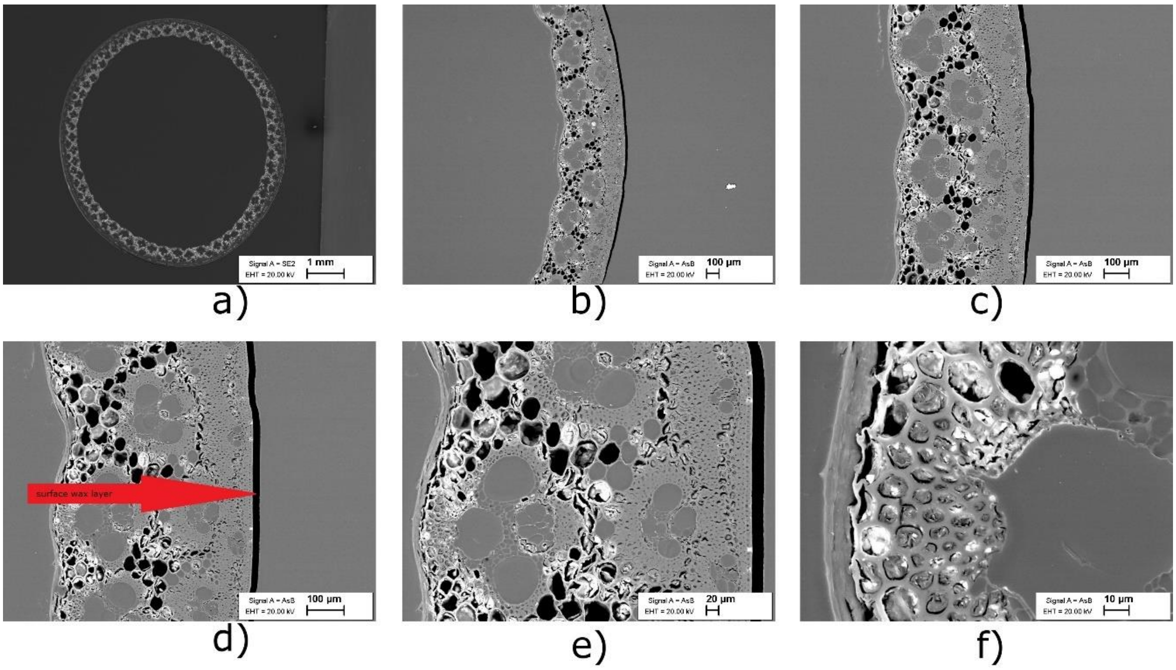


Figure 3.10 Laser engraved and coloured straws after durability testing: (a) 30x magnification; (b) 100x magnification; (c) 200x magnification; (d) 300x magnification; (e) 500x magnification (f) 2000x magnification

3.7 Optical microscopy properties

With optical microscopy 10x magnification was used for longitudinal section and 4x magnification for cross-section as seen in Figure 3.11 and Figure 3.12. The results were visually analysed. The straws without any laser engraving treatment have a nice smooth surface without any damaging. It can be seen that the straw with laser engraving has a rougher and more uneven surface compared to the straw without any treatment. This is due to the pattern engraved with laser engraving machine. When comparing the coloured straw with the one that has been tested for durability, no big changes are seen. The colour is still alike on both specimens which confirms that the food colour has penetrated deep into the surface and doesn’t wear off that easily.

Straws that were first thermally modified and then coloured have no visual changes after durability testing which also confirms that this treatment method gave a positive result also after being inside a drink for a longer period of time (Figure F.21). Straws that were oven dried with the excess colour not removed, had also good results after durability testing where the colour didn’t wear off (Figure F.22).

PME Orange (Figure F.23) gave a light orange pigment to the engraved patterns on the straws which can be seen very well on the longitudinal section after the durability testing on picture c where the part without any pattern is lighter and the part with engraved pattern is darker with orange pigment on it.

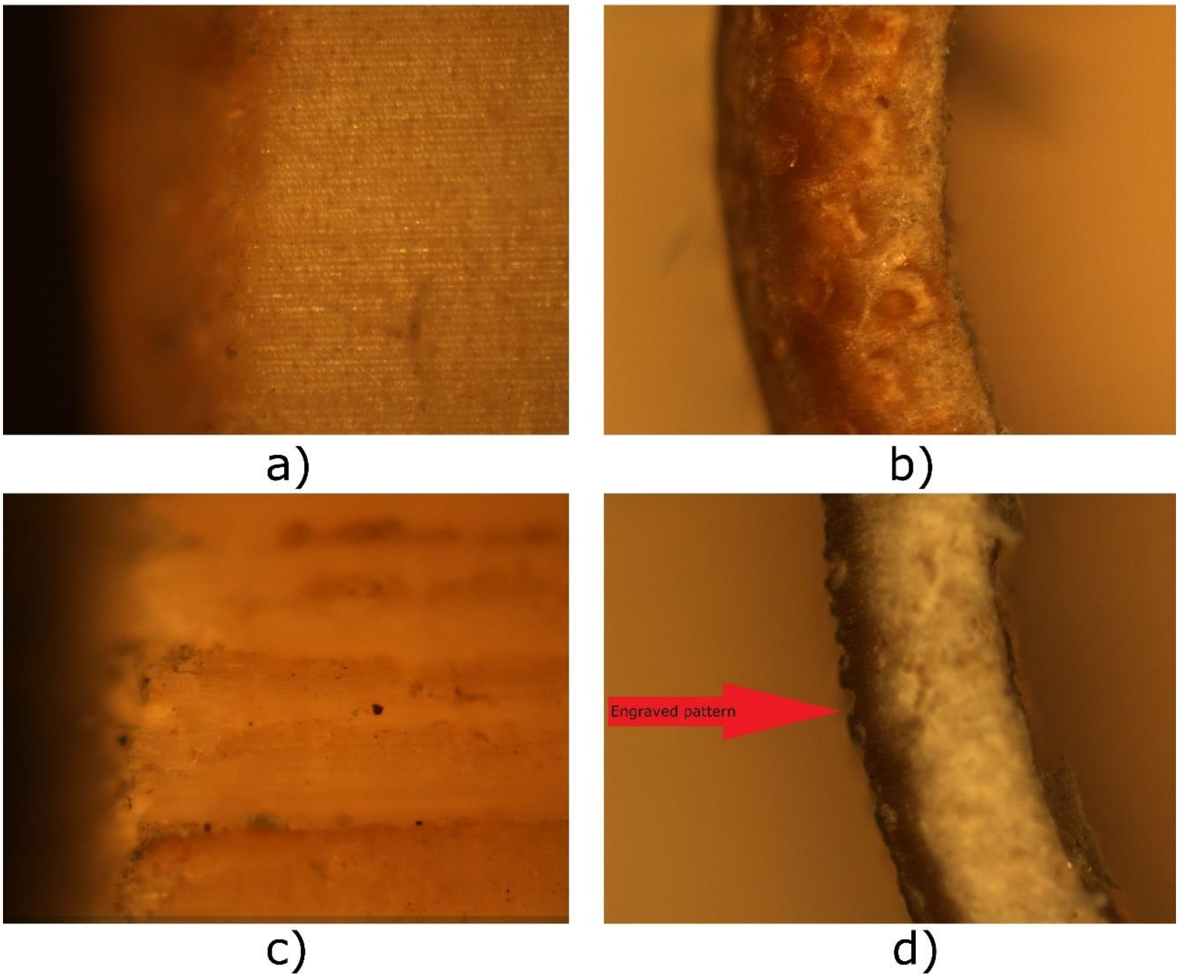


Figure 3.11 Optical microscopy results for laser engraved straws: (a) longitudinal section of straw without laser engraving, 10x magnification; (b) cross-section of straw without laser engraving, 4x magnification; (c) longitudinal section of straw with laser engraving, 10x magnification; (d) cross-section of straw with laser engraving, 4x magnification;

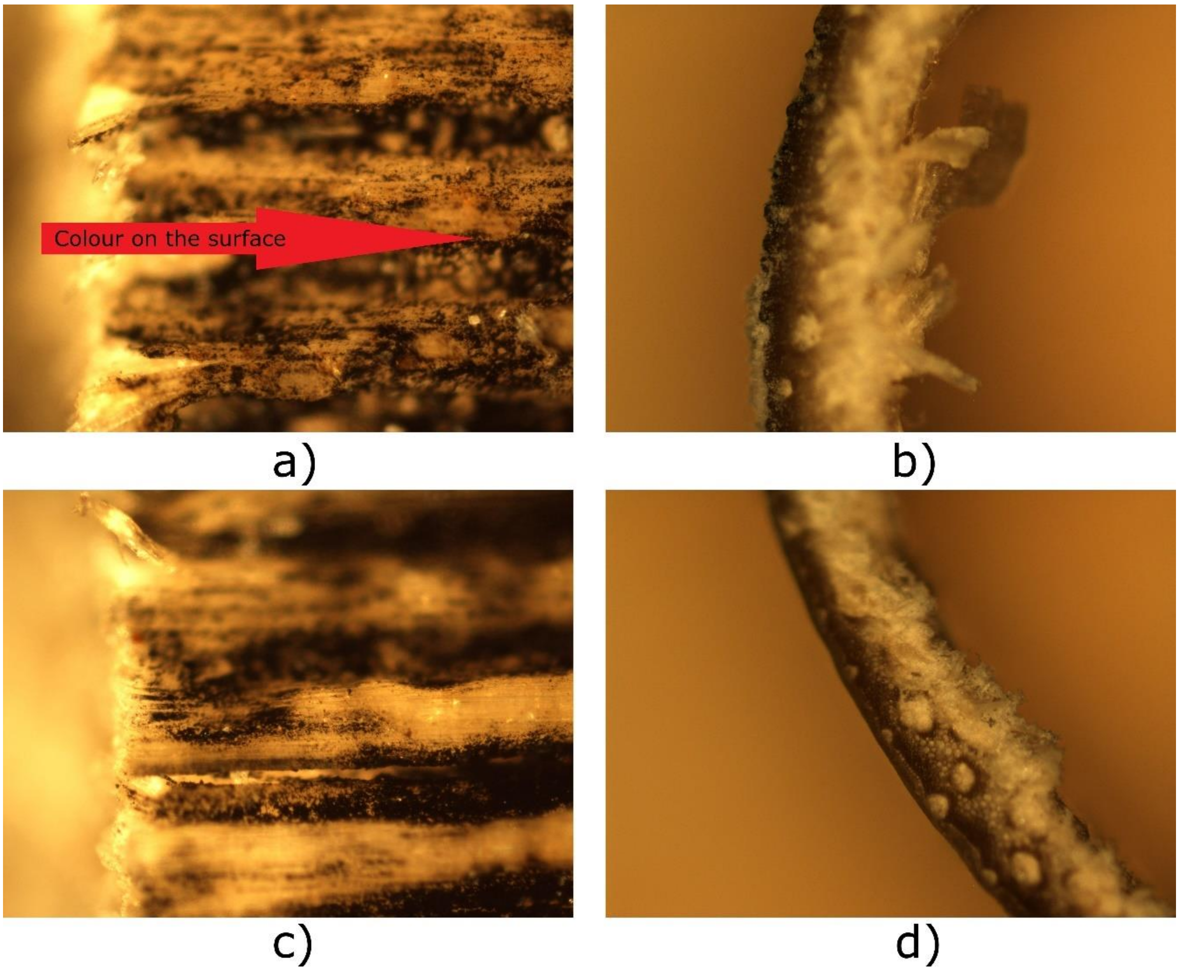


Figure 3.12 Optical microscopy results for laser engraved straws. PME Black colour was held on straws for 1 hour, then excess colour was removed with dry paper napkin and then the coloured straws were oven dried for 1.5 hours at 100°C: (a) longitudinal section of straw after colouring, 10x magnification; (b) cross-section of straw after colouring, 4x magnification; (c) longitudinal section of straw after durability tests, 10x magnification; (d) cross-section of straw after durability tests, 4x magnification

3.8 Estimating price

Different factors affect the end price of the laser engraved and coloured straws. The factors are: design cost, laser engraver time and cost, oven electricity cost, paint cost and labour cost as seen in Table 3.5.

The prototyping cost was calculated on the basis of a 16 cm long reed straw. It was calculated how much costs the production of 100 straws with different engraved and coloured patterns. The electricity and colour consumption were relatively low compared to the straws raw material and labour costs. With the calculation it was taken into consideration that 3 rows of the same pattern is made on each straw which makes the engraving time longer and colour consumption bigger. The end cost was 79.87 € which makes the price of making one straw approximately 0.79 €.

Table 3.5 Costs for making 100 design straws

Article	**Raw material cost**	**Measuring unit**	**Quantity**	**Unit cost**
Reed straws (16 cm)	0.30 €	Piece	100	30 €
Laser engraver electricity consumption	0.0225 €	Piece	100	2.25 €
Colour	3.50 € /25 g	g	0.18	2.52 €
Oven electricity	~ 0.3 €	€/1 h	1.5 h	0.10 €
Labour cost	10 €	Piece	4.5	45 €
			Total:	79.87 €

The end cost will be definitely lower when the straws are made by mass production. With mass production the laser engraving should be done with a rotating conveyor device so a worker doesn't have to rotate the straws manually which saves time and labour costs.

CONCLUSIONS

The aim of this study is to develop reed drinking straws with different natural finishing materials. The research was done in order to determine how the reed straws surface wax layer can be removed so that the natural finishing materials can penetrate through the surface and fasten on the straw.

During the colouring tests of the full straws it started to become obvious that it is really difficult to remove the wax surface from the reed straw so the colour would penetrate through and fasten on the surface. Hence the testing of the laser engraved straws.

Laser engraving the patterns on the straws removed the protective wax layer from the reed surface and allowed the food colours to penetrate deep enough so it lasts also in durability tests.

Thermal modification of the straw showed that higher temperatures (160°C) change the surface colour darker and these temperatures shouldn’t be used if the colour darkening is not a wish. Therefore lower, 100°C, temperatures should be used when oven drying the straws.

Durability tests showed that not all natural food colours are suitable to withstand long periods inside a drink. For example Sugarflair Pink that had a very satisfying colouring results with a bright pink colour, but wear off in the first hour inside a drink.

Estimating price showed that the end price for one straw is approximately 0.79 € which leaves it competitive and the end market price is still affordable for most of the clients who are willing to pay a little extra for a sustainable product.

With laser engraving and colouring the straws there were three different methods that gave very satisfying results, so from these three methods the most optimal way to treat the straws is as follows – first laser engrave the pattern on the straws, then colour the patterns with a small brush with PME liquid colour and leave the colour on the straws for one hour. After that remove the excess colour with a dry paper napkin and put the straws to oven dry for 1.5 hour at 100°C.

In conclusion, further research on industrial production should be conducted to see which rotating conveyor device is best suitable for this kind of production process.

SUMMARY

This research was engaged by an Estonian company Sutu OÜ whose main product sold is a reed drinking straw. In this research, product development of the reed straws was conducted from a development plan up to durability testing to add value to the straws. Tests were done to determine how the pectins can be removed from the reed straw surface coating so the natural finishing materials can fasten on the straw surface and withstand durability tests.

Investigating the competitors showed that reed straw is the cheapest natural straw that can be also reused. The closest competitor, bamboo straw, price is 50% higher compared to reed straw. At this moment there is no similar product on the market where a natural and biodegradable straw has an engraved design on it which is also coloured and this will give a huge advantage to the company on the competitive market.

During the development and testing it came obvious that the surface protective wax can’t be removed with the treatments that were found when researching the literature since no toxic chemicals can be used that are not suitable for food industry, but were used in all the methods found.

Designing the collections for reed straws was an alternative to colouring full straws. With designing the collections, the patterns were build upon natural shapes and textures which evolved into three collections – abstract, geometry and special collection. Patterns were made on the straws with laser engraving machine. Extra value was added with colouring the engraved patterns with natural food colours.

Durability tests were necessary to confirm if the food colours withstand being in a drink for longer period of time. Tests showed that not all the colours fastened on the reed surface and only positive results can be used with the production.

Further research on laser engraving machine rotating conveyor device is necessary to make the production faster and less dependent on people.

KOKKUVÕTE

Antud magistritöö telliti Eesti firma Sutu OÜ poolt, kelle peamine müüdav toode on pilliroost joogikõrred. Antud uurimistöös valmistati ette pilliroost joogikõrre tootearenduse plaan, et lisada kõrtele müügiväärtust. Kõrtele tehti erinevaid katseid, et teada saada kuidas oleks võimalik eemaldada pilliroost kõrte pinnalt seda kaitsev vahakiht, et naturaalsed viimistlusmaterjalid kinnituksid paremini kõrre pinnale ja peaksid vastu ka püsivuskatsetele erinevates jookides.

Konkurentide analüüs näitas, et pilliroost joogikõrred on kõige soodsamad naturaalsed kõrred turul, mis on ka taaskasutatavad. Lähima konkurendi, bambusest joogikõrre, hind on pilliroo kõrrega võrreldes 50% kõrgem. Praegusel hetkel ei ole turul sarnast toodet, mis oleks naturaalsest materjalist ja biolagunev ning millele on tehtud laseriga kujundus, mis on hiljem ka värvitud. See annab firmale väga suure eelise oma turul.

Tootearenduse käigus selgus, et pilliroo pinnalt ei ole võimalik seda kaitsvat vahakihti väga hästi eemaldada kuna kirjandusest leitud meetodite puhul kasutati inimesele mürgiseid kemikaale, mis tuli antud katsete puhul välja jätta, sest tegu on toidutööstuses kasutatava tootega.

Laseriga tehtud kujunduse kollektsioonid on alteratiiviks pillirookõrte üleni värvimisele. Kollektsioonide mustrid tuletati suuresti loodusest leitavatest kujudest ja faktuuridest. Kokku on kolm kollektsiooni – abstraktne, geomeetriline ja erikollektsioon. Mustrid on kõrrele tehtud laseriga. Lisaväärtuse annab laseriga tehtud mustrite üle värvimine toiduvärvidega.

Püsivuskatsed olid vajalikud, et kinnitada kas kõik testitud toiduvärvid peavad vastu pikema perioodi erinevate jookide sees. Katsed näitasid, et mitte kõik värvid ei kinnitunud pilliroo pinnale sama hästi. Ainult positiivse tulemusega värve saab edaspidi asutada tootmises.

Tulevikus tuleks uurida ja vajadusel arendada laserile pöörlev konveier, mis muudaks mustrite tootmise kõrre pinnale kiiremaks ja ka vähem sõltuvaks inimestest.

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APPENDICES

Appendix A. Colouring properties of full straws

a) b)

c) d)

Figure A.1 Straws with 10 min pre-treatment in boiling water, then 24 hours inside pigment: (a) matcha powder; (b) adjika sauce; (c) chopped spinach; (d) blackcurrant

a) b)

c) d)

Figure A.2 Straws with 10 min pre-treatment in 30 % vinegar solution, then 24 hours inside pigment: (a) grape juice; (b) beet juice; (c) cherry juice; (d) crush blackcurrants

a) b) c)

Figure A.3 Straws with NaOH pre-treatment, then soaked in natural PME liquid food colour: (a) 5 min in NaOH; (b) 10 min in NaOH; (c) 15 min in NaOH

Figure A.4 Straws with microwave oven pre-treatment, then soaked in PME liquid food colour

Figure A.5 Straws without pre-treatment, sprayed with 50/50 PME White paste/water solution with spray gun

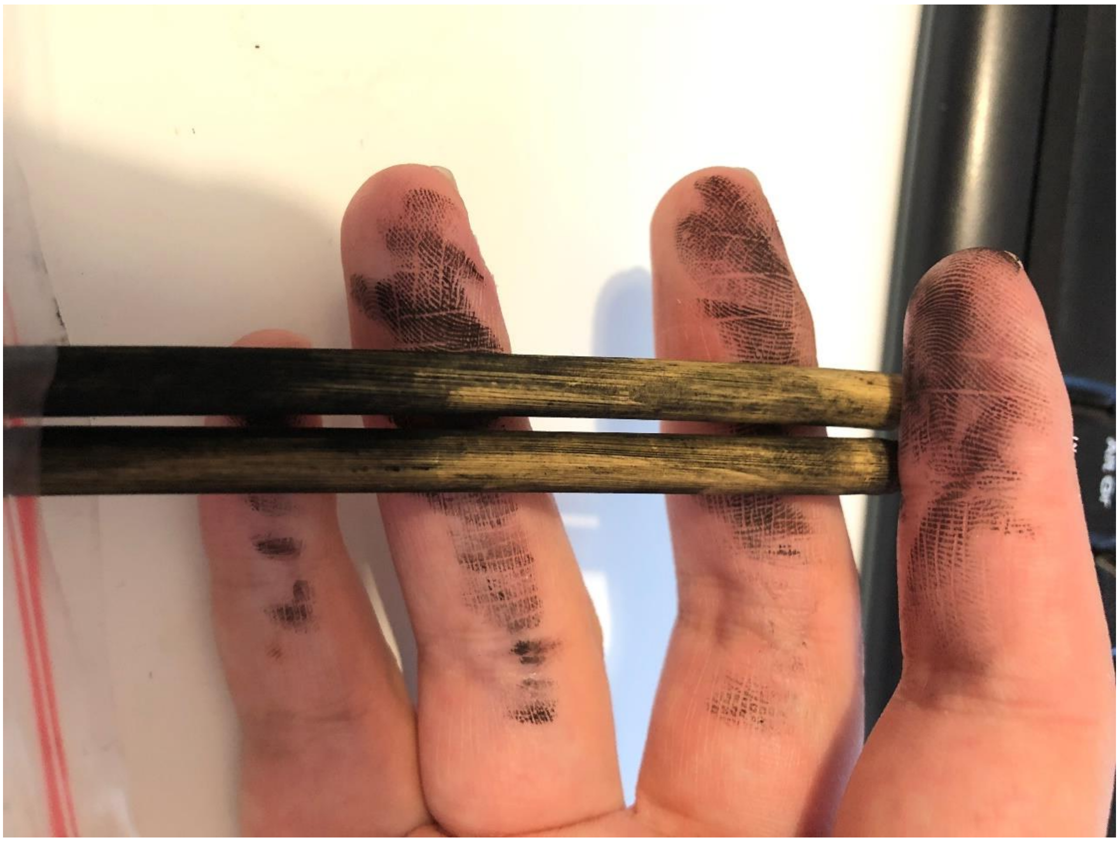

Figure A.6 Straws without pre-treatment, boiled with 1 tbs of PME Black liquid food colour for 18 min

Figure A.7 Straws without pre-treatment, boiled with 1 tbs of PME Juniper Green liquid food colour for 30 min

Figure A.8 Straws without pre-treatment, boiled with 1 tbs of spirulina powder for 20 min

Figure A.9 Straws without pre-treatment, coloured with Porcelan Art porcelain colour

Figure B.10 Laser engraved straws with no pre-treatment inside beetroot juice for 3 hours

Figure B.11 Laser engraved straws with no pre-treatment inside cherry juice for 3 hours

Figure B.12 Laser engraved straws with no pre-treatment covered with spirulina powder and a drop of water for 3 hours

a)

b)

c)

Figure B.13 Laser engraved straws coloured in different natural food colours: (a) PME Orange; (b) PME Moss Green; (c) Sugarflair Pink

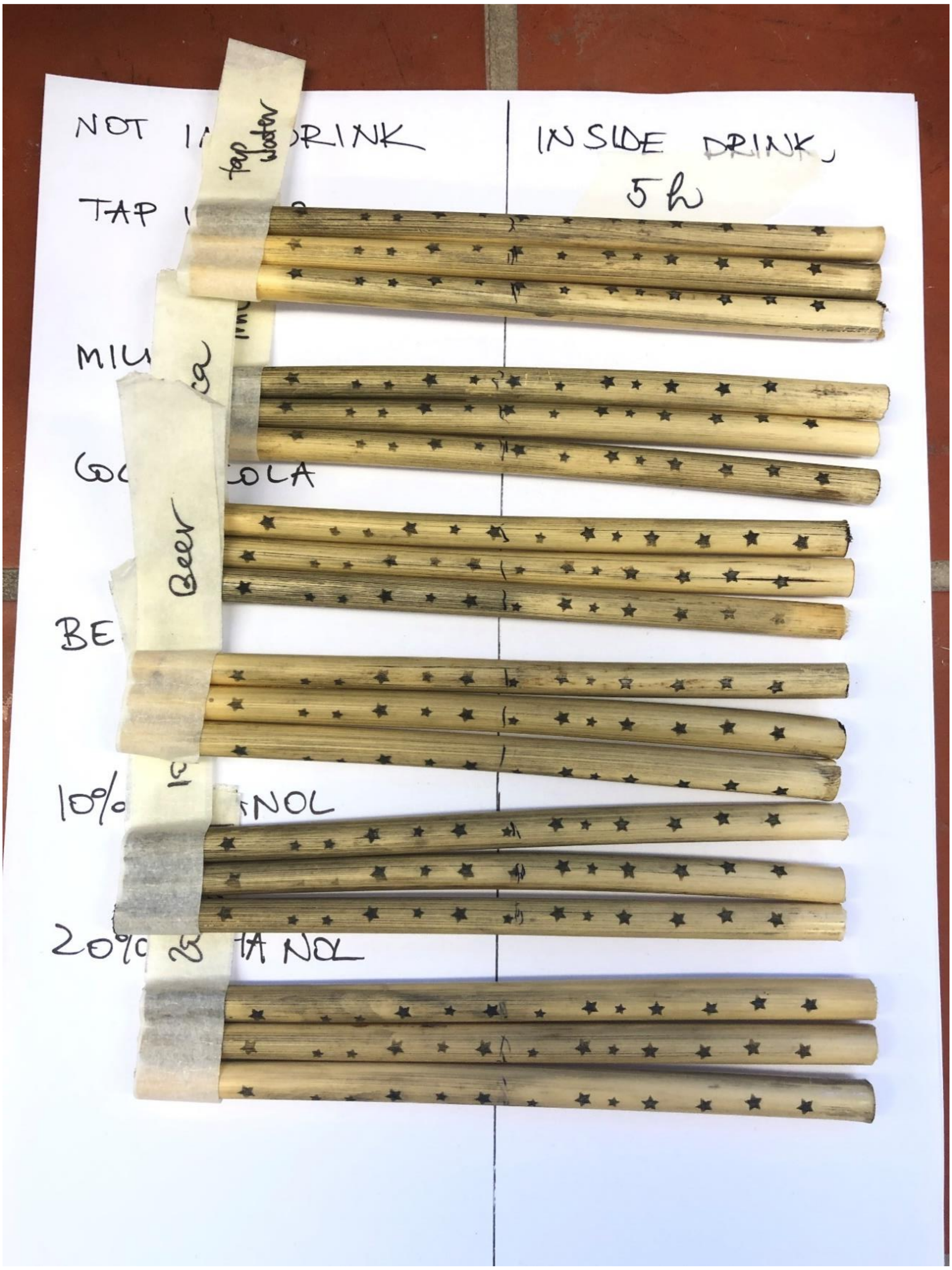

Figure C.14 Straws with PME Black after 5x 1 h drink test and 5x wash test (straws that are thermally modified before colour for 1 h at 100°C, colour oven dried after the excess colour was removed with a paper napkin for 1.5 h at 100°C)

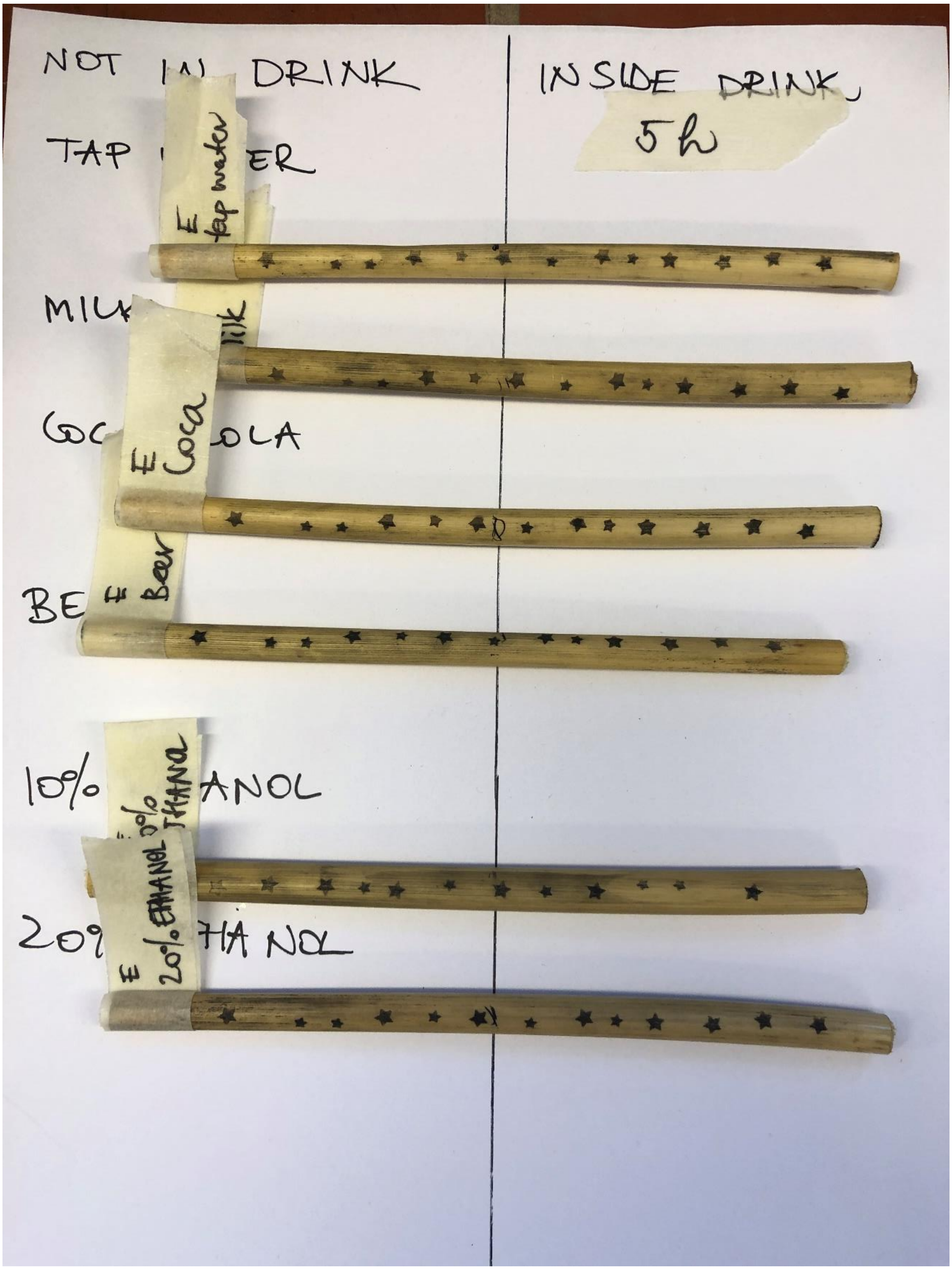

Figure C.15 Straws with PME Black after 5x 1 h drink test and 5x wash test (straws that are thermally modified before colour for 1 h at 100°C, colour oven dried with excess colour for 1.5 h at 100°C)

Figure C.16 Straws with PME Orange after 5x1 h drink test and 5x wash test (straws that are thermally modified before colour for 1 h at 100°C, colour oven dried for 1.5 h at 100°C)

Figure C.17 Straws with PME Moss Green after 1x 1 h drink test and 24 extreme condition test inside water at 70°C for 24 hours (colour oven dried after the excess colour was removed with a paper napkin for 1.5 h at 100°C)

Figure D.18 Straws after warehouse test

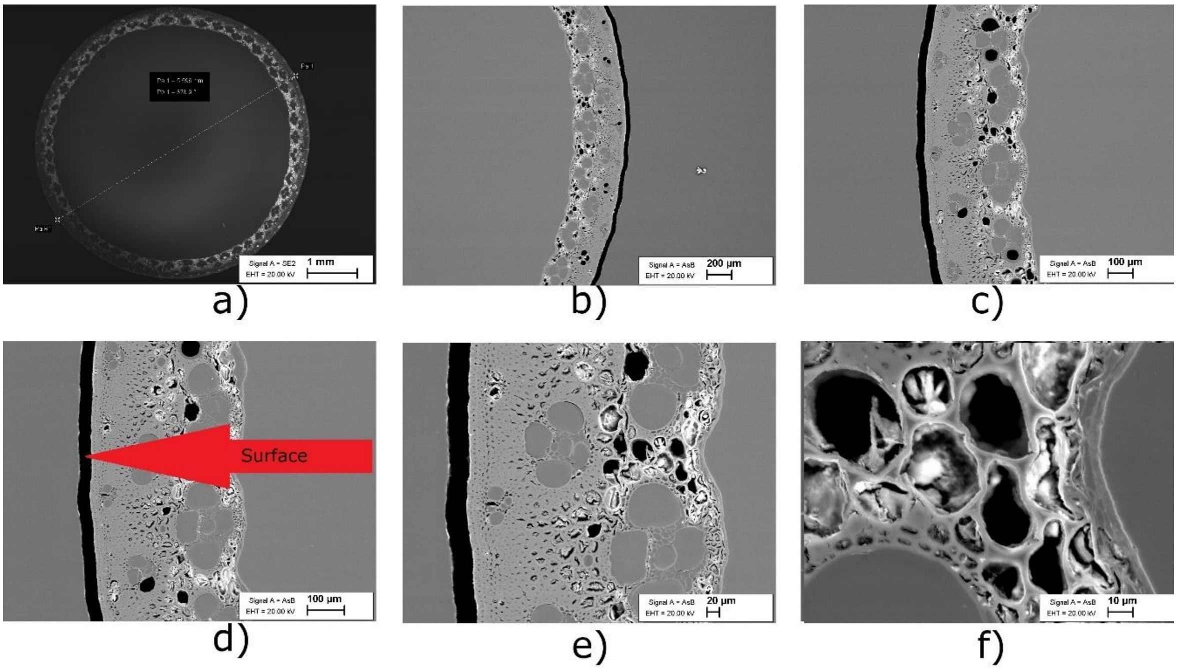

Figure E.19 Straws boiled with PME Juniper Green liquid food colour: (a) 40x magnification; (b) 100x magnification; (c) 200x magnification; (d) 300x magnification; (e) 500x magnification; (f) 2000x magnification

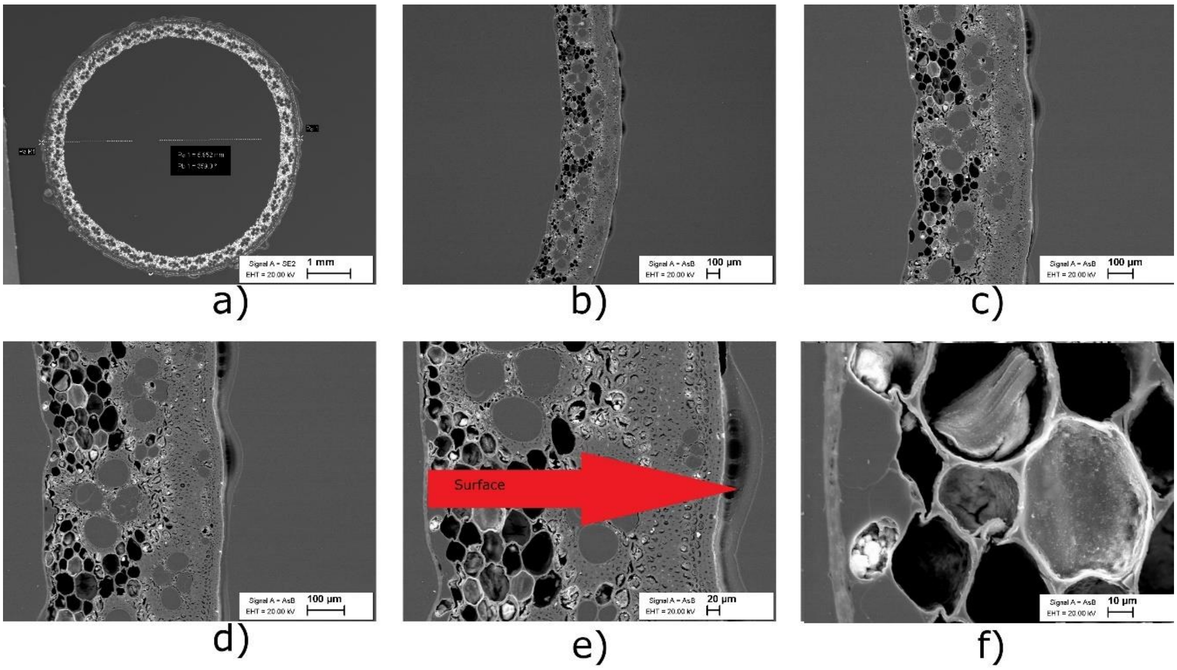

Figure E.20 Straws coloured with Porcelan Art porcelain colour: (a) 35x magnification; (b) 100x magnification; (c) 200x magnification; (d) 300x magnification; (e) 500x magnification; (f) 2000x magnification

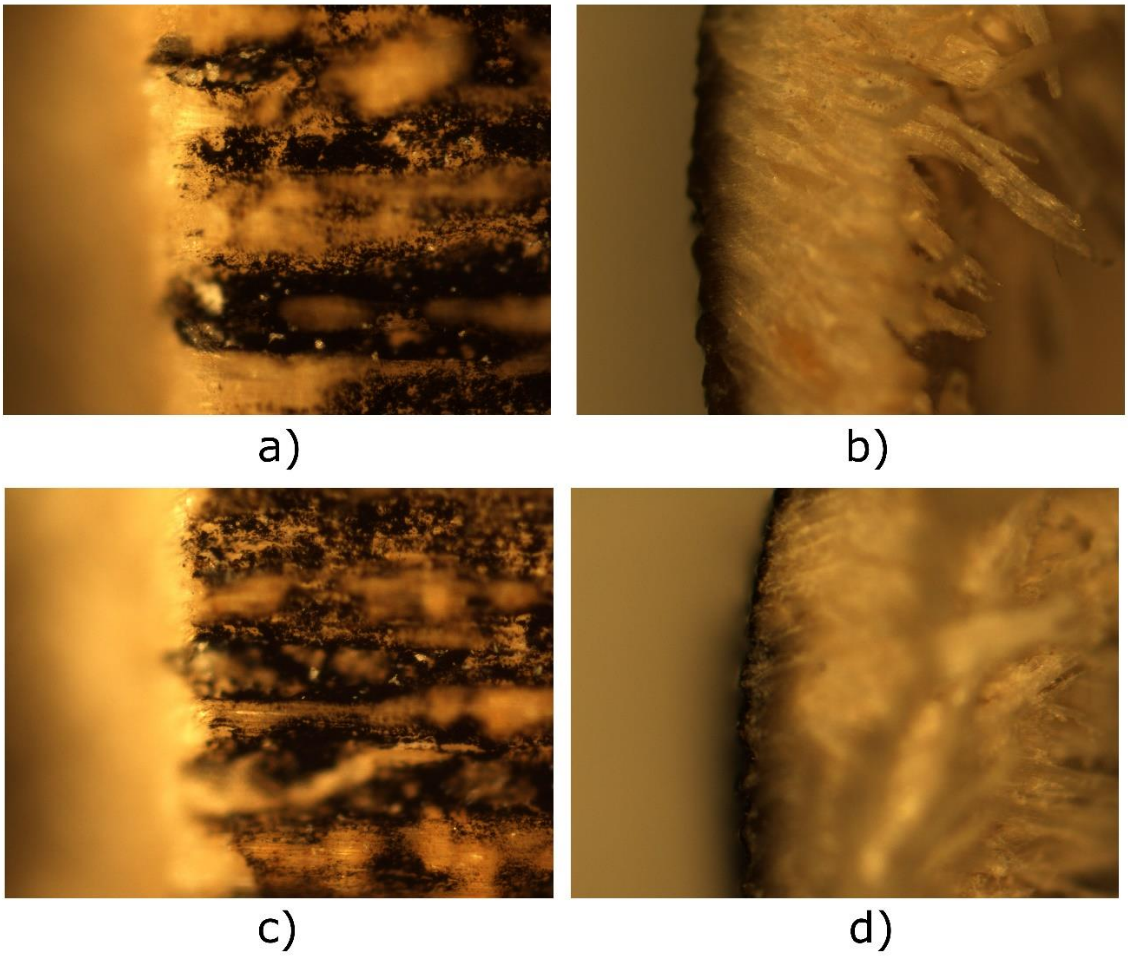

Figure F.21 Optical microscopy results for laser engraved straws that were thermally modified for 1 hours at 100°C before colouring. PME Black colour was held on straws for 1 hour, then excess colour was removed with dry paper napkin and then the coloured straws were oven dried for 1.5 hours at 100°C: (a) longitudinal section of coloured and dried straw, 10x magnification; (b) cross-section of coloured and dried straw, 4x magnification; (c) longitudinal section of straw after durability testing, 10x magnification; (d) cross-section of straw after durability testing, 4x magnification

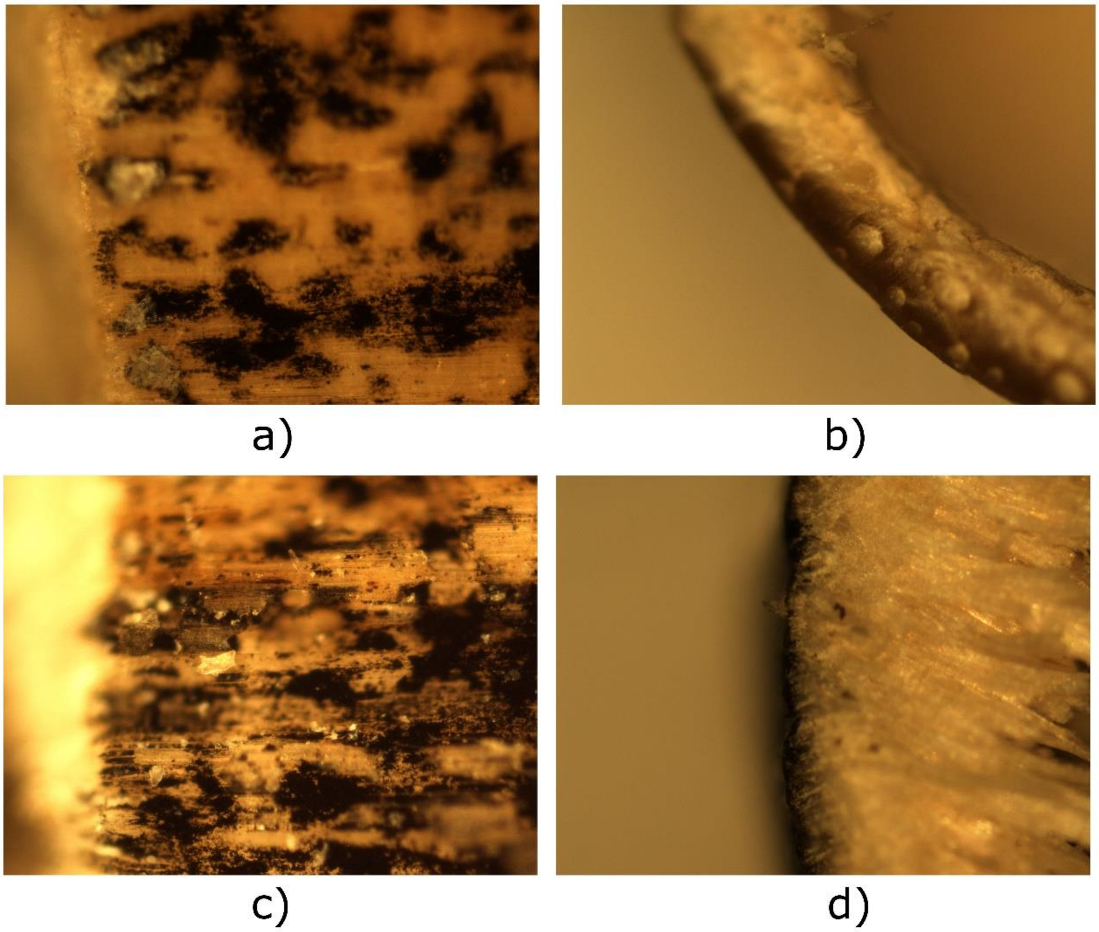

Figure F.22 Optical microscopy results for laser engraved straws that were thermally modified for 1 hours at 100°C before colouring. PME Black colour was held on straws for 1 hour and then the coloured straws with excess colour were oven dried for 1.5 hours at 100°C. Excess colour was removed after oven drying: (a) longitudinal section of coloured and dried straw, 10x magnification; (b) cross-section of coloured and dried straw, 4x magnification; (c) longitudinal section of straw after durability testing, 10x magnification; (d) cross-section of straw after durability testing, 4x magnification

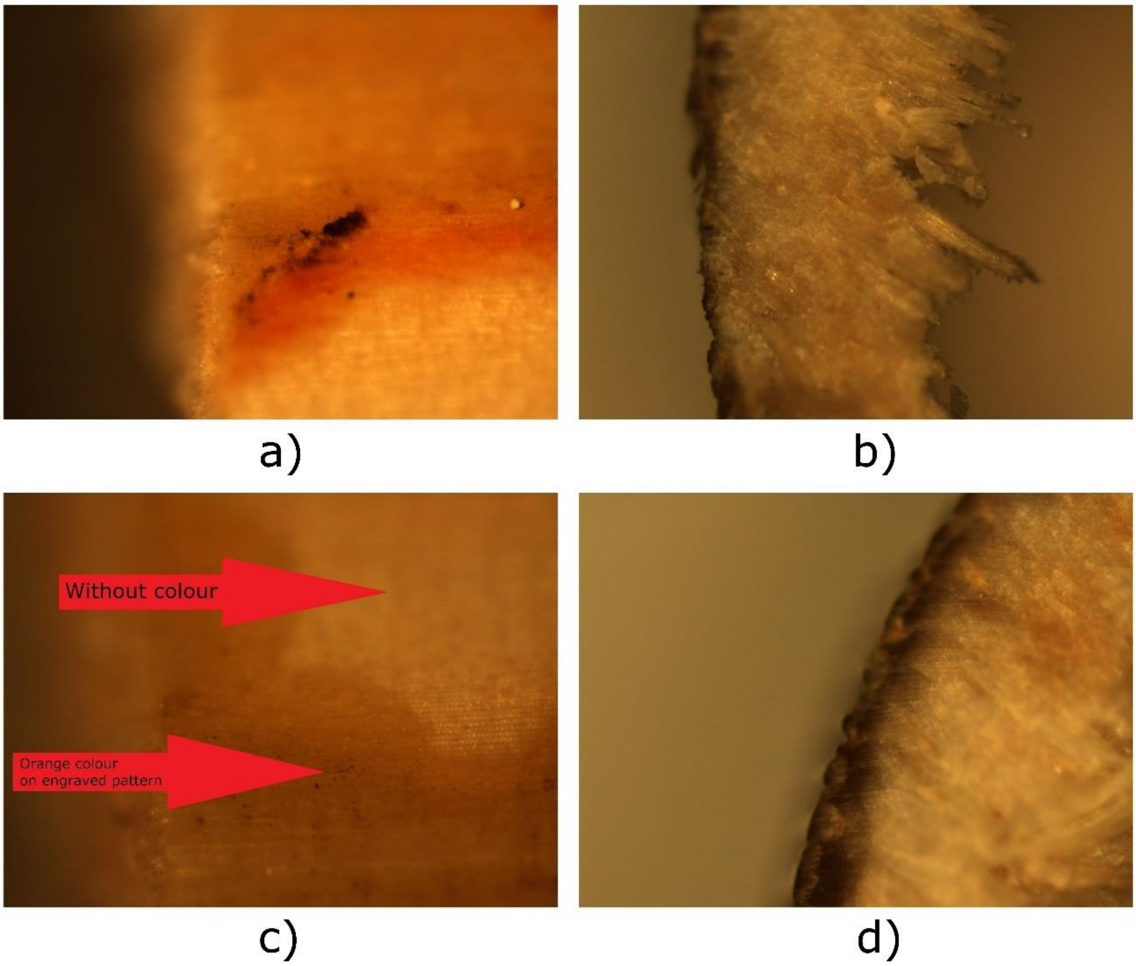

Figure F.23 Optical microscopy results for laser engraved straws that were thermally modified for 1 hours at 100°C before colouring. PME Orange colour was held on straws for 1 hour, then excess colour was removed with dry paper napkin and then the coloured straws were oven dried for 1.5 hours at 100°C: (a) longitudinal section of coloured and dried straw, 10x magnification; (b) cross-section of coloured and dried straw, 4x magnification; (c) longitudinal section of straw after durability testing, 10x magnification; (d) cross-section of straw after durability testing, 4x magnification