the CHEMARTS Cookbook

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(Eds.)

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the CHEMARTS Cookbook

DEDICATION

To all the Aalto University CHEMARTS students who have contributed to this book and inspired us all to work with new materials.

CHEMARTS

CHEMARTS is the long-term collaboration project of two Aalto University schools: the School of Chemical Engineering (CHEM) and the School of Arts, Design and Architecture (ARTS). These schools combined forces in 2011 with the aim of researching bio-based materials in an innovative way and creating new concepts for their advanced use. The core values of CHEMARTS are the sustainable use of natural resources, experimental working methods, and the respectful cross-pollination of design and material research.

CHEMARTS arranges multidisciplinary study courses and a Summer School for degree students, thesis projects, and workshops for elementary and high school students. It also participates in externally funded research projects. The recipes of **The CHEMARTS Cookbook** were developed and tested by students and staff in 2014–2019 in the CHEMARTS Laboratory in Finland.

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FOREWORD

In the coming years, our material world will change dramatically. In parallel with climatechange, our lifestyles will also change. The overuse of existing raw materials cannot continue and global consumption must decrease. However, our need for materials will not disappear: in the future too, they will come to nurture us, cover us, comfort us, delight us, and keep us alive. This means we need many new ideas, collaboration across all borders and hard work to replace our existing material systems and consumption habits with more sustainable ones. In many cases, bio-based materials are considered the best alternative to currently dominant fossil-based ones. To facilitate this change, we should be curious about what products are made of and about the origin of materials. Knowledge and transparency is urgently needed in all phases of production processes.

The good news is that the new era has already begun: awareness of ecological issues is increasing, recycling is becoming part of our everyday routines, and materials now play a role in several United Nations Sustainable Development Goals. Renewable raw material sources and unused side streams or waste are being researched around the globe. More and more designers and other creative minds are becoming engaged in innovative material research and development processes, together with scientists and engineers. We – the CHEMARTS team – are part of this movement, and through this book we want to share our experiences by focusing on the topic we know best: materials from the forest.

The CHEMARTS team

We warmly encourage playful, hands-on experiments and further development of our recipes. Always remember work safety!

1 INTRODUCTION

Experimenting with foam.

Working at CHEMARTS *lab in the Aalto University.*

HOW TO USE THIS BOOK

Pirjo Kääriäinen & Liisa Tervinen

This is a book about wood- and plant-based materials, especially cellulose. Here in Finland we are specialists in this field: 70% of our country is covered by forests (of which we strive to take good care). In recent years, interest in the innovative use of mechanically or chemically processed wood-based materials has increased, and a new start-up scene has emerged. We can use our existing expertise in materials for completely new applications, and with this book we aim to inspire future professionals to explore this potential.

In this first chapter, *Introduction*, we explain the basics of wood-based materials, and briefly discuss scientific and designerly methods in material research, a realm traditionally dominated by scientists and engineers. Recently, many designers have become excited about experimental material design, often driven by the need to find more sustainable material solutions. However, designers have often worked alone or within the designer community, without proper support to further develop and scale-up their most feasible ideas. At the same time, scientific material research has resulted in ground-breaking findings, which, with help from designers, could be applied in everyday life. As collaboration is crucial for the future, we want to share some tips on how to carry this out in practice.

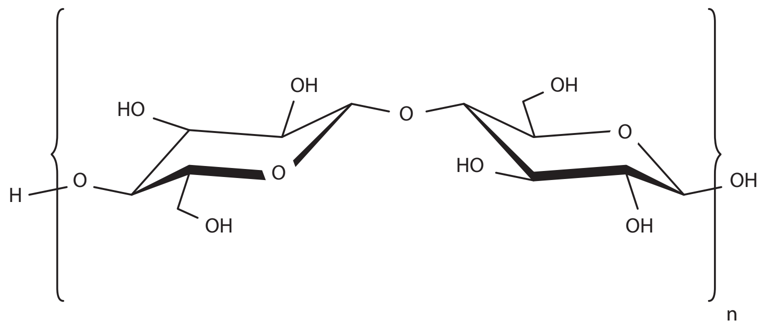
The second chapter, *Working with Materials*, presents the required spaces and tools, the ingredients, some of the basic methods used in the recipes, and most importantly of all: safety rules. The heart of this book is Chapter three, *Recipes*, where you'll find 27 recipes and methods for hands-on experiments. It contains both simple and more advanced recipes, organized according to their targeted properties: Hard, Soft, Flexible, etc. and is divided into two categories based on their complexity and recommended work environment: Workshop and Laboratory. All the recipes are designed for experiments only and result in a only small amount of material samples. After your first trials, you can expand the recipes into larger quantities or develop your own experiments. Please remember to always consider work safety. As some of the ingredients and tools are not easily accessible, some recipes require close collaboration with a company or research institute. The final chapter of this book is for *Inspiration*, and contains examples of student projects, research cases and three company stories.

We warmly encourage playful, hands-on experiments and further development of our recipes. Be prepared for failures: they are unavoidable! In the best case, they'll provide new ideas and even a totally new direction for your project.

Get inspired and have fun!

BASICS OF WOOD-BASED MATERIALS

Iina Solala & Tapani Vuorinen



CREDITS: NINA RIUTTA

Plants are formed from small cells that are glued together with pectin and/or lignin polymers (large molecules that consist of one or more repeating units, or monomers). The walls of plant cells are structured from cellulose fibrils that are mostly surrounded by hemicelluloses and lignin. These polymers form the nanocomposite structure of the cell wall, the properties of which also depend on how the cellulose fibrils are organized in the several sublayers of the cell wall. To illustrate the scales of the cell wall structures a barely visible, 1–3 mm long wood fibre contains on average circa 1 km of cellulose fibrils.

Cellulose is the most common biopolymer and consists of long, linear chains of glucose sugars joined together by glycosidic bonds. The degree of polymerisation (DP, the number of repeating units in a molecule) in wood is about 10 000. Due to strong intermolecular forces, cellulose molecules aggregate together to form semicrystalline microfibrils and then cells, mostly fibres – the main structural unit in plants. Cellulose interacts strongly with water, owing to the large number of hydroxyl groups it contains (three OHs per glucose unit). When in water, cellulose swells and softens, but does not dissolve.

Through different types of chemical and physical modifications, it is possible to produce cellulose materials with varying textures, feels, transparencies, and formability properties. Cellulosic materials have been used industrially for a long time, and include various grades of paper pulp used for printing and packaging, cotton fibres in textile manufacturing, and numerous chemical derivatives of cellulose (cellulose acetate, methyl cellulose, carboxymethyl cellulose, etc.) which may possess plastic-like properties or dissolve in water. Different types of nanocelluloses (nanocrystalline cellulose, nanofibrillar cellulose, bacterial cellulose) are a newer addition to this family of materials, the potential products of which range from composites, gels, emulsions, and barrier films to cosmetics and biomedical applications.

Hemicelluloses are cell wall polysaccharides that have structural similarity to cellulose but consist of several different sugars – not only glucose but also mannose, xylose, arabinose, galactose, etc. Unlike cellulose, the linear hemicellulose chains carry small substituents, mostly sugars but also acetyl groups. In comparison with cellulose, hemicellulose chains are short, consisting of only 100–400 monomer units. Their substituents make hemicelluloses amorphous and easier to dissolve than long and mostly crystalline cellulose.

Lignin is a branched polyaromatic molecule that glues plant fibres together and enables water transport in living plants. The structure of lignin varies according to its source and chemical processing, but its DP has been estimated at about 100. Unlike cellulose and hemicelluloses, lignin is hydrophobic, 'water-fearing', and can be used to decrease the water uptake of cellulosic materials. In living plants, lignin and hemicelluloses together control the water content of the cell wall.

In addition to cell wall polymers, plants contain several other substances for photosynthesis (chlorophyll), energy storage (starch, sugars, fats), biological defence (terpenes, terpenoids, phenols), and attracting pollinators (sugars, colour pigments).

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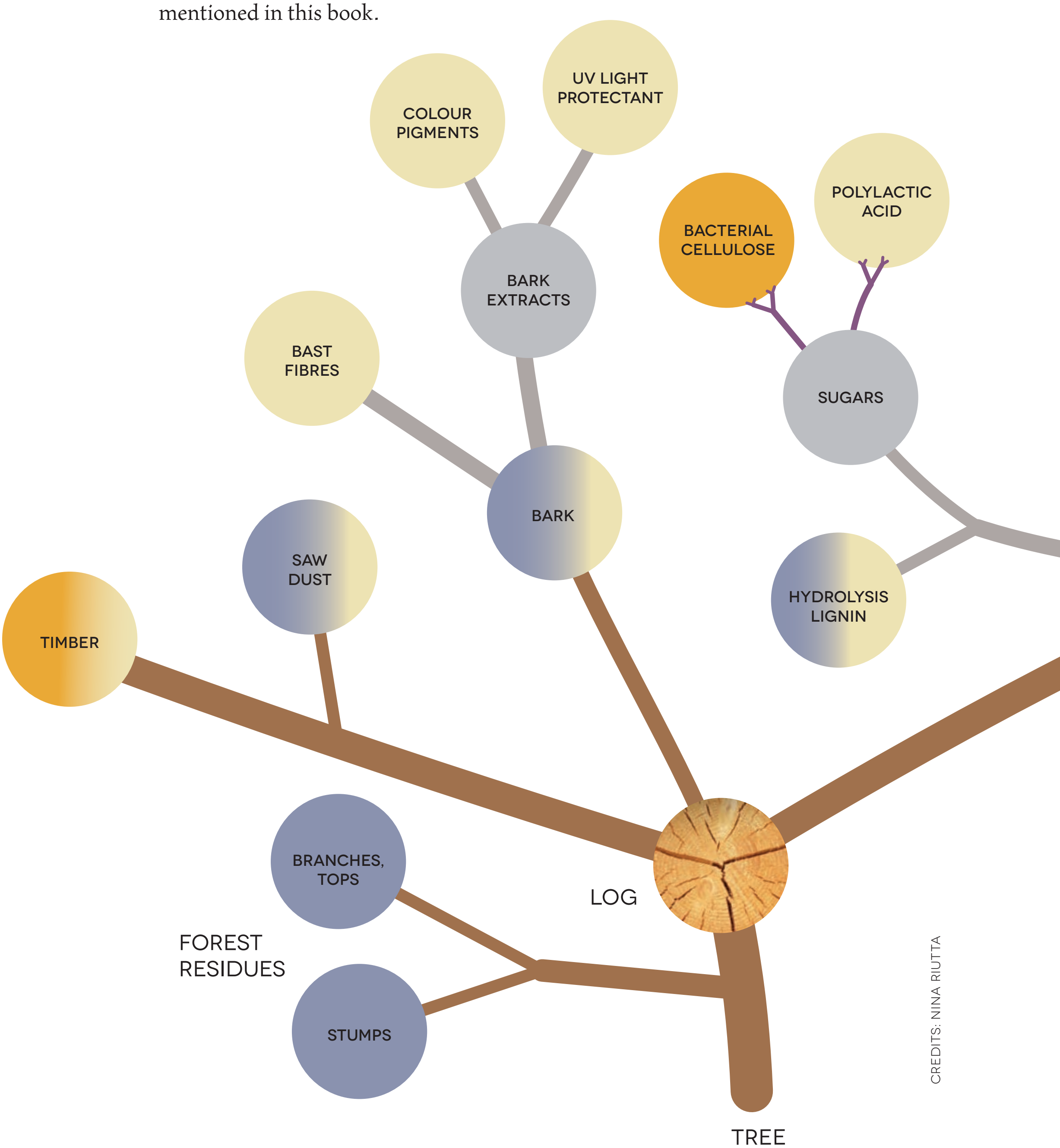
Walter de Gruyter, Berlin and New York Klemm D, Heublein B, Fink HP, Bohn A (2005) Cellulose: Fascinating biopolymer and sustainable raw material. Angew Chemie – Int Ed 44:3358-3393

Klemm D, Kramer F, Moritz S, et al (2011) Nanocelluloses: A new family of nature-based materials. Angew Chemie – Int Ed 50:5438-5466. Ralph J, Brunow G, Boerjan W (2007) Lignins. John Wiley & Sons, Ltd.

PROCESSING OF WOOD BIOMASS

Tapani Vuorinen & Nina Riutta

The processing of wood biomass into the various materials and products mentioned in this book.



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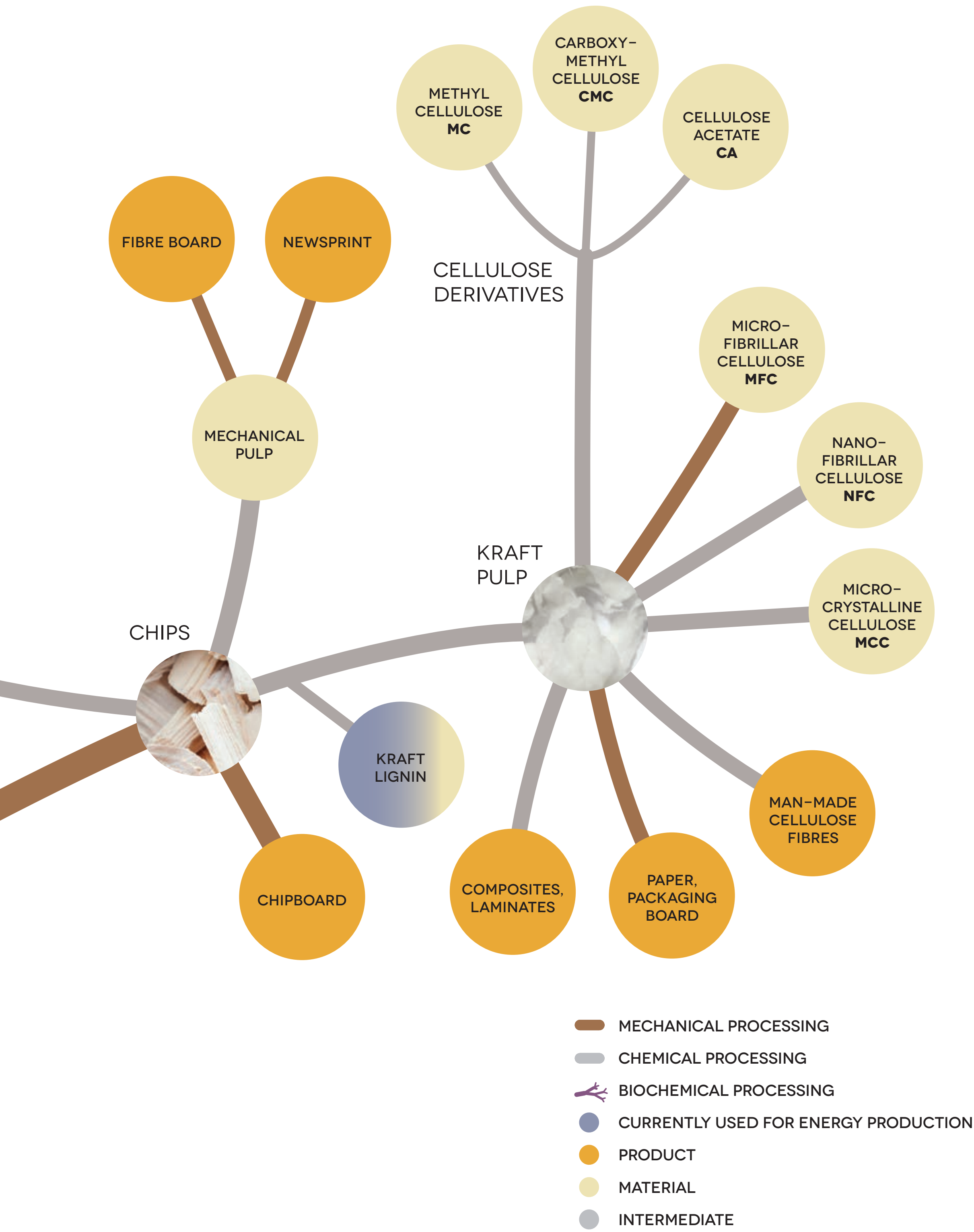


CARBOXY-METHYL CELLULOSE **CMC**
METHYL CELLULOSE **MC**
CELLULOSE ACETATE **CA**
FIBRE BOARD
NEWSPRINT
CELLULOSE DERIVATIVES
MICRO-FIBRILLAR CELLULOSE **MFC**
MECHANICAL PULP
NANO-FIBRILLAR CELLULOSE **NFC**
KRAFT PULP
CHIPS
MICRO-CRYSTALLINE CELLULOSE **MCC**
KRAFT LIGNIN
MAN-MADE CELLULOSE FIBRES
CHIPBOARD
COMPOSITES, LAMINATES
PAPER, PACKAGING BOARD
MECHANICAL PROCESSING
CHEMICAL PROCESSING
BIOCHEMICAL PROCESSING
CURRENTLY USED FOR ENERGY PRODUCTION
PRODUCT
MATERIAL
INTERMEDIATE

SCIENTIFIC MATERIAL RESEARCH: PRINCIPLES AND PRACTICES

Tapani Vuorinen & Iina Solala

Science aims to increase and organize knowledge to understand complex systems and phenomena and predict their consequences. It adds to existing knowledge and challenges it to identify and correct possible errors in the common understanding. Honest peer evaluation is an essential part of the scientific approach – nothing is true before the community has accepted it; and even then, the truth may later change on the basis of new findings. These principles lead to several practices that make the scientific approach quite heavy and fragmented.

Building on existing knowledge requires a scientist to be aware of others' work in the same area. Being unaware is not an excuse; it is a sign of laziness in studying scientific literature. Scientists need to document and report their experimental methods, experimental results and justifications in such detail that others in the scientific community can prove or disprove their conclusions. As a result, a single scientific study often concerns a certain part or detail, and not a complete complex system or phenomenon.

Material science deals with the fundamental properties of matter, and its engineering and uses in various applications. When working with wood- or other plant-based materials, properties such as the content and degree of the polymerisation of the main components (often cellulose, lignin and hemicelluloses), water uptake and wettability, porosity, crystallinity, polymer and fibril orientation, and tensile and compression stiffness are important. To acquire information on these, materials scientists utilize a number of analytical techniques which each have advantages and limitations that must be known for them to be applied effectively.

When working in a multidisciplinary setting with designers, material scientists may think their role is to direct the experimental work towards new discoveries by utilizing their in-depth knowledge of material properties and characterisation to form hypotheses on how different components could be combined to achieve a desired functionality, and to test these hypotheses systematically. However, material scientists also willingly admit that a designer perspective is valuable for defining the material properties to be studied for a target application, as designers tend to approach things from a very different, visual and tactile perspective, taking inspiration from the inherent properties of a material and developing them further. These thoughts often hold true, and we have found that design students can also make scientifically important observations by experimenting on something that scientists do not consider interesting.

DESIGNERLY APPROACH TO MATERIAL RESEARCH

Pirjo Kääriäinen

Experimental material projects and material design are becoming increasingly popular among designers, expanding the design profession. Designers use their imagination and skills to utilize waste streams, for example, or to create new materials from unexpected sources. In addition to material development projects, designers and artists use speculative design and design fiction to present alternative material futures and to raise awareness of the urgent need for sustainability. Instead of offering solutions, they ask questions and encourage their audience to react – and act.

Designers are considered creative, curious about new things and capable of a holistic approach to solving problems. They are usually trained to have skills for prototyping (mock-ups, modelling, etc.) and for visual communication. When confronting a new material, a designer needs to understand its properties and behaviour to understand how it could be applied. Material libraries provide data on the properties of commercial and experimental materials, but when working with totally new materials, this knowledge often needs to be gained through hands-on experiments.

A typical designerly way to approach material is to process it in as many ways as possible, and to analyse the results and its physical and sensory qualities before entering into the next cycle of experiments. Often, failures or unexpected material behaviour open up completely new perspectives to material development processes. This kind of iterative approach builds up new knowledge regarding the material and might result in surprising outcomes. However, this method also requires sufficient quantities of the physical material to play with, which might be a challenge in early-stage material development when only a few precious drops of the material might be available.

Strategic use of design methods and tools can speed up material development projects, and in the best case, provide new – even radical – concepts and applications. Unfortunately, designers sometimes fail to properly document their working processes, which might prevent further development and cause problems for commercialization; for example, when agreeing on intellectual property rights (IPR).

Design is also a powerful tool for communication and for implementing collaborative processes with companies and other stakeholders. No matter how simple prototypes are, they enable discussions and help others understand how the material could be used in the future. The value of visual information such as infographics, photographs, videos, and exhibitions should not be underestimated.

↑ *Displaying* CHEMARTS *Summer School 2019 processes and results. Samples by Xuyang Zhang.*
↓ *Designers' hands-on work in the* CHEMARTS *lab.*

TIPS FOR COLLABORATION

Pirjo Kääriäinen & Liisa Tervinen

The problems we face today are often so complicated and multi-layered that they can't be tackled without versatile expertise. The need for experts with a clear focus on narrow research topics will not disappear, but the world will also increasingly need experts who are open to dialogue and collaboration. For example, if you are a designer, you don't have to be an expert in material science; you can always seek collaboration, views and opinions in areas that are unfamiliar to you. If you are a chemist, you can invite a designer to join your project to help with process development, possible applications and user experience, not forgetting aesthetic and sensorial aspects.

Here we share some tips on how to collaborate in practice.

BE BRAVE AND DECIDE TO ASK FOR OPINIONS. When you are deep inside your own topic, it's often useful to get an outsider's view to reveal new angles, and in the best case, to create something completely new.

GATHER INFORMATION BEFORE CONTACTING POTENTIAL PARTNERS. Familiarize yourself with the existing knowledge related to your project, and also with your potential partner's expertise. This way you can construct your questions and argue your ideas effectively.

PREPARE FOR MEETINGS. When meeting potential collaboration partners, you need to be prepared to present your own work and to explain why you are interested in working with them. Collaboration needs to be meaningful for all partners: what can the partners gain from shared activities?

NOTE THAT ALL TEAM MEMBERS NEED RESOURCES. When planning new collaboration, openly discuss funding, timeframes and other resources as early as possible.

DISCUSS INTELLECTUAL PROPERTY RIGHTS (IPR). Even if you don't create inventions or set up business cases, credit need to be given to all who have participated in the process and the outcome.

FIND WAYS TO WORK TOGETHER, SIDE BY SIDE. This is the key to successful collaboration.

LEARN A NEW LANGUAGE. Collaborating with others, especially those from other disciplines, is not easy: it often involves a great deal of miscommunication and misunderstandings. This needs to be approached in the same way as learning a new language; it requires an open mind and heart, patience, and plenty of practice.

BE CURIOUS, CHERISH DIVERSITY AND SHOW RESPECT. Always respect your collaborators' knowledge and opinions; you learn the most by listening and sharing.

2

WORKING WITH MATERIALS

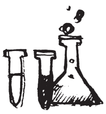
SPACES AND TOOLS

Pirjo Kääriäinen, Nina Riutta, Tapani Vuorinen & Liisa Tervinen

The recipes are divided into two categories based on their complexity, recommended working environment and required tools. These categories are: *Workshop* and *Laboratory*. The more you explore, the more you may want to try out and it may be worth investing in some more advanced tools and materials. Wherever you work with material experiments, always make sure you use protective gloves and clothing, and that the space in which you are working has proper ventilation (see Chapter Cooking rules and safety). Some recipes in the *Workshop* category are also suitable for trying out also with school children.

WORKSHOP

It is useful to have a space dedicated for CHEMARTS Cookbook experiments. You need a table, stove or hotplate, and water tap with a water tap. Maybe you have access to a specific workshop space or a makerspace in which you can conduct wet experiments. If you decide to work at home, all you need is basic craft or cooking tools, but please note that you should never use the same equipment that you have used for your material explorations afterwards for preparing food. Cover worktops with baking paper or brown paper used in renovations and use an apron to avoid stains. Natural colours, for example, might stain your garments.



LABORATORY

For the most advanced recipes in this book, you will need access to a professional laboratory. These can be found at schools, universities or other research institutes working in material research. Expertise and equipment vary according to their research focus. To obtain access to these facilities, you may need to participate in a course, set up collaboration with researchers, or become part of a research project. In professional laboratories you can use a broader range of chemicals and access state-of-the-art equipment such as kraft pulp cooking machinery for pulping, or a Masuko grinder for microfibrillar cellulose. Make sure to always follow the instructions provided by the space owner.

BASIC TOOLS

Bowls
Pans
Measuring cup and scales
Craft knives, spoons, spatulas, scissors
Brushes
Hand blender
Syringe
Hotplate or stove
Filtration fabric or/and a bag made from it
Protective gloves and clothing
Tape and markers for marking your samples

ADDITIONAL EQUIPMENT (DEPENDING ON THE RECIPE)

Papermaking frame
Thermometer
Pliers and cutters
Magnetic stirrer and magnet
Ready-made or self-made moulds
Colander
Hot press
Oven
Refrigerator
Grinding mill or a mortar
Fume hood

Filtration fabric – or a filtration fabric bag – is mentioned in several recipes as a tool for removing excess water from the material mixtures. Select a filtration fabric with a mesh count high enough to hold in the mixture and allow water to pass through, like the synthetic fabrics used in silkscreens or a thin nylon or polyester fabric. A small bag made of this fabric is also useful.

MATERIALS

You can buy craft materials such as paper, wool, yarns and dyes from a craft store, or starch, baking soda and food colours from a grocery store. You can also use kitchen leftover materials such as vegetable peels or coffee grains, or materials from nature such as willow branches or plants. Use your creativity but be sure to remember safety.

Some materials might be difficult to access, in which case you can approach companies or research institutes.

Cooking the inner bark of willow to separate bast fibres.

Material samples drying in laboratory oven.

INGREDIENTS

Tapani Vuorinen, Pirjo Kääriäinen & Nina Riutta

The following list presents the ingredients used in The CHEMARTS Cookbook recipes, and provides examples of how they are commonly used today. Most of the recipes utilize cellulose in different forms as well as other bio-based polymers, as they are non-toxic, readily available, renewable, and biodegradable. We have used abbreviations to shorten the long chemical names of the cellulose-based materials.

PULP

PULP is a mixture of plant cells from the mechanical or chemical treatment of biomass, for example, wood chips. Newspapers and fibreboards, such as medium-density fibreboard (MDF), are examples of products made from mechanical pulps. Chemical pulps have a broader spectrum of uses: printing and tissue paper, cardboards for packaging, laminates and composites, fibrillar and crystalline cellulose, man-made cellulose fibres (textiles), and various cellulose derivatives. The *kraft* process, referring to the treatment of biomass at a high temperature with a mixture of sodium hydroxide and sodium sulphide, is the most commonly used method for producing chemical pulps. Softwood kraft pulps consist of 2–3 mm long plant fibres and a small amount of tiny parenchyma cells. Hardwood kraft pulps contain 1 mm long fibres, parenchyma cells and vessel elements which are broad, thin-walled cells. Unbleached kraft pulps are brown in colour whereas bleached kraft pulps are white. White tissue paper is almost pure bleached pulp. Optical microscopy of pulp or tissue paper reveals its origin as softwood or hardwood.

For transportation and storage, chemical pulp mills dry the pulp in a few millimeter-thick sheets, and pack them in bales. For the next processes, such as papermaking, the dried pulp sheets are soaked in water and mixed vigorously: mixing separates the cells from each other. Vacuum filtration or pressing through a tight mesh removes excess water from the wet pulp.

Wet pulp

Microfibrillar cellulose (MFC)

NANOCELLULOSE

Nanocellulose is not a singular material; several materials have micro- or nano-structured fibrils. Some of these are explained below:

NANOFIBRILLAR CELLULOSE (NFC) is a (semi)transparent gel of cellulose fibrils in water. The preparation of NFC includes two steps: the oxidation of bleached chemical pulp and a subsequent mechanical treatment. The oxidation of the pulp with sodium hypochlorite, catalysed by TEMPO (a sterically hindered tertiary amine), forms carboxylate groups on cellulose fibrils, which increases their hydration. Mild mechanical treatment then separates the fibrils easily from each other.

NFC gels consist mostly of water. Their dry material content (DMC) is typically 3% or less, depending on the carboxylate content, that is, ca. 1 mol/kg or more (on dry matter). Vacuum filtration or mechanical pressing does not remove water from NFC. If NFC is treated with an acid (final pH 3 or less), the gel becomes non-ionic and binds less water. After this, excess water separates spontaneously from the gel. Concentrated salt solutions may have similar dewatering effects on NFC. Drying of the gel leads to irreversible aggregation of the fibrils.

MICROFIBRILLAR CELLULOSE (MFC) is an opaque mixture of cellulose fibrils in water. Extensive mechanical refining or grinding of dilute chemical pulp suspensions is the most common way of producing MFC. The treatment consumes a great deal of energy because the plant fibre walls are strong and difficult to fibrillate. Pretreatment with cellulase enzymes weakens the fibre wall and reduces the mechanical energy consumption. Using pulps of thin-walled cells, such as the residue from potato starch production, enables the production of MFC with much less energy.

MFC consist mostly of water. Its DMC is typically 5% or less. Vacuum filtration or pressing through a tight textile may partly remove the water. Drying of MFC leads to irreversible aggregation between the fibrils.

CELLULOSE DERIVATIVES USED IN CHEMARTS RECIPES

CARBOXYMETHYL CELLULOSE (CMC) powder is the most common water-soluble derivative of cellulose. CMC has a multitude of technical applications such as that of a thickener, emulsifier or binder in, for example, paints and paper products. CMC is widely used in food and cosmetic products; for example, in ice cream and toothpaste. CMC may form aggregates with ionic particles. The solubility of CMC and the viscosity of its solutions in water depend mostly on polymer chain length.

CELLULOSE ACETATES (CA), for example **CELLULOSE TRIACETATE (CTA)** and **CELLULOSE DIACETATE (CDA)**, are plastic-like materials. They are water-insoluble derivatives that are available in the form of flakes or powder. CTA and CDA are soluble in organic solvents: CTA in chloroform and CDA in acetone or its mixture with ethanol. When dried, CTA forms fully transparent films, whereas CDA films may be slightly milky. Hot pressing is another technique for making CTA films and composites. **CELLULOSE ACETATE BUTYRATE (CAB)** is a cellulose derivative that is suitable for composites due to its low melting temperature. Cigarette filters are a major application of cellulose acetates.

HYDROXYPROPYL CELLULOSE (HPC) powder is a non-ionic, water-soluble cellulose derivative. Its solution properties are quite similar to those of methyl cellulose, and include the temperature dependence of solubility in water. Aqueous HPC solutions are used in eye drops, for example, for the treatment of dry eyes.

METHYL CELLULOSE (MC) powder is another cellulose derivative that is soluble in water at a low temperature. MC has technical applications similar to CMC such as a thickener, binder or emulsifier. MC is used in, for example, construction materials such as mortars, plasters and wallpaper pastes but also in food and cosmetic products. When heated, MC solutions solidify, which allows the drying of their foams into a desired shape. Unlike CMC, MC is a non-ionic polymer and suitable binder for all particles, independent of their ionic charge.

MICROCRYSTALLINE CELLULOSE (MCC) is a wet slurry or a dry powder of small rod-like cellulose particles. Extensive acid treatment of bleached chemical pulp leads to the cutting of cellulose fibrils to short nano-sized rods and their aggregates, which form the cellulose particles. Ultrasonic treatment of MCC suspension breaks the aggregates and reduces the particle size. MCC is used in, for example, the pharmaceutical, food and cosmetic industries as a binder, bulking additive, stabilizer, or abrasive.

Various wood-based materials

OTHER MATERIALS USED IN THE RECIPES

BAKING SODA is a white sodium bicarbonate powder that is commonly used in baking as a raising agent in, for example, doughs and batters. Heating releases CO_2 gas from the baking soda which gives the baked product its characteristic fluffy texture. Heating of aqueous solutions of baking soda leads to bubbling and increased solution alkalinity; from pH8 to pH10. Mixing baking soda with acids also releases CO_2.

CALCIUM CARBONATE is better known as limestone, chalk or marble. In addition to these natural sources, precipitated calcium carbonate (PCC) is produced through the carbonation of hydrated lime or slake (calcium hydroxide). PCC has a higher purity than the natural sources of calcium carbonate. It is non-toxic and can be used as a component in medical and food products and as a filler and coating pigment in papers and boards, including those used for food packaging. Calcium carbonate is almost insoluble in water, but dissolves completely in acid media.

GLYCEROL is a natural component of fats and a byproduct in the production of soap, fatty acids and their methyl esters. Glycerol has a low melting point (18 °C) and high boiling point (290 °C) which makes it suitable as a non-volatile softener in bio-based materials. It is soluble in water and commonly used in cosmetics.

NATURAL RUBBER, caoutchouc, is a natural product made from the latex of certain tropical plants. The properties of rubber include high strength and elasticity. Traditionally it has been used to produce water-proof, elastic products and coatings, and today it is often substituted by fossil-based materials such as synthetic elastomers.

POLYLACTIC ACID (PLA) is the most commonly used bio-based plastic for replacing polyethylene (PE) and other non-biodegradable, synthetic polymers. It has become a popular replacement for traditional oil-based plastics in, for example, food packaging. PLA is biodegradable but degrades more slowly in nature than most biopolymers. PLA is a linear polyester of lactic acid (DP 15-150) that is typically derived from fermented starch by ring-opening polymerisation. Although PLA is currently mainly produced from corn starch syrup, cane sugar or sugars in general can be used as its raw material.

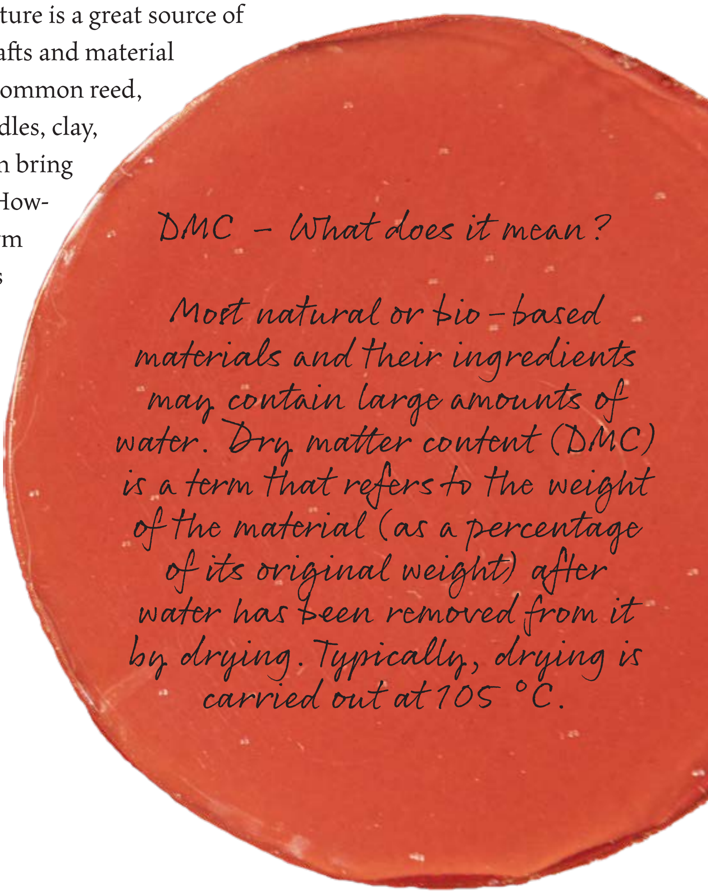
SODIUM DODECYL SULPHATE (SDS) powder is a common, synthetic surfactant, a molecule that has a small hydrophilic head and hydrophobic tail. SDS can be used in the process of producing and stabilizing foams.

STARCH is a white flour-like powder that is commonly obtained from maize, cassava or potatoes, for example. However, all green plants store chemical energy in starch granules that consist of varying amounts of two non-cell wall polysaccharides – linear amylose and branched amylopectin – both of which are formed of glucose only and have a high DP. The granules gelatinize when heated and may partly dissolve. Starch is widely used in food products, as a thickener in sauces and puddings, for example, and in the paper industry to add strength to paper.

BAST FIBRES: All plants contain fibres that give mechanical strength to the stem and other anatomical parts of the plant. Bast fibres are continuous, thin aggregates of plant fibres bound together by lignin. They are present in the stems of several annual plants, such as flax, hemp and nettle, but also in the inner bark of some trees, such as linden and willow. However, the length of bast fibres varies depending on the plant species. For example, in the last annual growth region of willows, these bundles can be as long as the tree itself. These kinds of fibre bundles are not present in most Scandinavian wood species, such as birch, pine or spruce. Field retting removes the pectins around bast fibres and enables their separation. Alternatively, cooking with baking soda has the same separating effect on some bast fibres.

MATERIALS DIRECTLY FROM NATURE: Nature is a great source of inspiration and is full of treasures for crafts and material experiments. For example, flowers, the common reed, algae, leaves, branches, moss, cones, needles, clay, earth, cones, seeds, berries, and grass can bring a surprising twist to your experiments. However, you must be very careful not to harm nature. Always collect needles and cones from the ground, and do not take plants with their roots intact. Naturally, you need the landowners' permission to take anything from private areas. Always leave rare species untouched.

And please remember that not everything that comes from nature is safe and healthy for human beings: be careful with toxic plants and mushrooms, to mention just a few potentially dangerous materials!



METHODS

Tapani Vuorinen & Nina Riutta

In CHEMARTS experiments, a few basic techniques have been proven to be highly useful. These techniques can be used to, for example, facilitate drying, control dimensional changes during drying and tailor material properties. If a material experimenter has a specific end use in mind, the most suitable processing methods can be selected beforehand, but sometimes when exploring a new material, testing various processes might be a good way of collecting ideas on its potential applications. Whatever your approach is, always look carefully at all the results; even the ones you consider failures. Your observations of the material may open up paths to new applications.

DRYING

Drying is an essential part of cellulose-based material research. At room temperature, most of the items we consider to be dry contain water. For example, paper contains 5–10% water depending on the paper type and the relative humidity of air. In cellulose-based raw materials, water content can be very high, up to 99%. This means that during drying, cellulose-based materials, such as nanofibrillar cellulose (NFC), might lose most of their weight. Evaporation of the water in room temperature takes time. At elevated temperatures, samples dry more quickly, but excessive heating often starts to discolour samples. Sometimes, drying for too long at a high temperature may negatively affect the material's properties.

Drying can be affected in various ways. Adding softeners like glycerol or filler particles, for example, starch or wood dust, helps to keep the shape and reduce shrinkage. Dimensional changes can also be controlled by pressing, moulding or using a vacuum oven or a freeze dryer that vacuum-dries frozen samples. To avoid attachment, dry on a non-stick surface such as a Teflon tray, silicone coated baking paper, or a petri dish made of polypropylene.

→ *Label material samples clearly and document experiments systematically. During this research, detailed notes were made about the material in a notebook and shared digitally.*

EXTRACTION FROM SOLID MATERIALS

Solvent extraction is a way of separating soluble substances from solid materials. Extraction is used in the production of natural colour pigments or to gather extracts with specific material properties, such as spruce inner bark extract for its UV protection ability. The solvent can be either water or an organic solvent such as ethanol or acetone, depending on the solubility of the extracts. Water extracts polar substances such as sugars and phenols from plants, whereas organic solvents dissolve non-polar compounds such as carotenoids and stilbenes. Many of these extracts can be used as colourants, UV protecting additives, or fragrances. The polar substances solubilize when minced plant material is heated or boiled in water. In the laboratory, non-polar compounds are extracted using organic solvents by a Soxhlet apparatus in a fume hood.

EXTRUSION

Extrusion is a manufacturing technique in which a viscous material is forced through a gap to produce a continuous shape. The technique is widely used in, for example, the polymer and food processing industry. Extrusion 3D printing can be applied for more complex shaping of paste-like materials. When exploring biopastes for extrusion, early tests can be conducted a piping bag, which is often used in baking. For example, microcrystalline cellulose pastes with wood dust, starch or glycerol have been shaped in this way.

FINISHING TOUCHES: COATINGS

Coating is a layer spread on top of a material, often to protect it from environmental factors. A coating enables improvement of, for example, water repellency; UV and corrosion resistance; and heat, cold, and chemical and fire resistance. Because many cellulose-based materials are sensitive to moisture, water repellency needs to be considered in several applications. Alternative biological substances that can provide sufficient hydrophobicity include carnauba wax and beeswax. Dispersions of these waxes can be applied to the surfaces of the materials by painting or spraying. Repeated treatments, with drying in between, improves protection. Other functionalities, such as UV protection, can be added to the coating formula.

Extruding material paste using a syringe.

Foaming experiments.

FOAMING

Foaming enables the creation of soft, light materials, both thick and thin. Mechanically mixing air with a fluid forms gas pockets which become trapped in the matrix. Surfactants and polymers or particles stabilize the foam. Drying stable foam makes it solid. Liquid foams are used in, for example, cosmetics, and solid polymer foams (plastics) in insulation, packaging and cushioning materials.

At home, you can easily create bio-based foams using a dishwashing liquid. In the laboratory, you can use pure surfactant powders such as sodium dodecyl sulphate (SDS). The do-it-yourself foaming process includes two main steps: mixing dishwashing liquid and moist material using a blender until an even foam appears, and dewatering the foamed shape in a mould or surface that enables excess water to drain away during the drying process.

GLUEING

Bio-based glues used are still rare, and glueing is one of the challenges when working with experimental bio-based materials. However, in some cases, glue is not even needed for a durable bindings. Most biological materials are hydrophilic and strongly associate with water: during drying, the hydrated particles and/or polymers bind together spontaneously. Smaller particle size and more extensive hydration lead to stronger bond formation. Thus, carboxymethyl cellulose (CMC) and nanofibrillar cellulose (NFC), for example, are excellent binders of hydrophilic particles and surfaces. However, when rewetted, these hydrophilic components rehydrate and lose their glueing effect.

Achieving a water-resistant glueing effect requires the use of more hydrophobic substances. Synthetic phenol-formaldehyde resins have been used in, for example, the production of plywood and laminates. The resin components can be replaced at least partly by aldehydes and phenols, which are derived from nature. In this respect, lignin has been used to replace phenol.

MILLING

The same material can provide different material properties, depending on its particle size. Sometimes it might be necessary to adjust particle size to better suit a specific processing method. For example, in 3D extrusion, particles that are too large may block the nozzle. In the laboratory, Wiley milling can make dry biological materials into either a rough or fine powder, depending on the mesh size of the screen used. A hand blender, a chopper, a coffee bean grinder or mortar and pestle all produce particles of less controllable size.

MIXING SOLIDS AND LIQUIDS

Whatever you do with materials, you will usually be mixing something. Many solid materials are insoluble in water or other solvents. Even soluble substances have limits to their solubility. When preparing solutions it is important to know the solubility of the components and the factors that affect the rate of dissolution. Typically, small particle size and heating make dissolution faster. Many polymers such as cellulose acetate or methyl cellulose dissolve slowly and may require mixing or standing overnight to obtain a clear solution. Sometimes raising the temperature negatively affects solubility; for example the solubility of methyl cellulose in water.

Insoluble particles often form aggregates or flocs that are difficult to disintegrate to form thick homogeneous mixtures. Pulp fibres disperse evenly in large amounts of water when mixed vigorously. After homogenisation, excess water can be removed by vacuum filtration or pressing through a tight mesh. It is also hard to accomplish even mixtures when particles are long, for example hemp fibres, as they become entangled during mixing. Shortening the fibres facilitates mixing. Sometimes mixing can create bubbles that may affect the material's properties.

MOULDING

Moulding means shaping soft substances into a particular form. The selection of the mould depends on the properties of the substance. In some cases, fluid substances can be cast in hollow moulds. When the substance solidifies as a result of cooling or drying, it takes the shape of the container. For example, some microfibrillar cellulose (MFC) shapes have been formed using hollow plaster moulds, and methyl cellulose (MC) foams have been shaped using hollow glass moulds. A mould can also be a shape in which the substance is layered. As cellulose-based materials shrink during drying, a positive draft facilitates the retention of the item's dimensions.

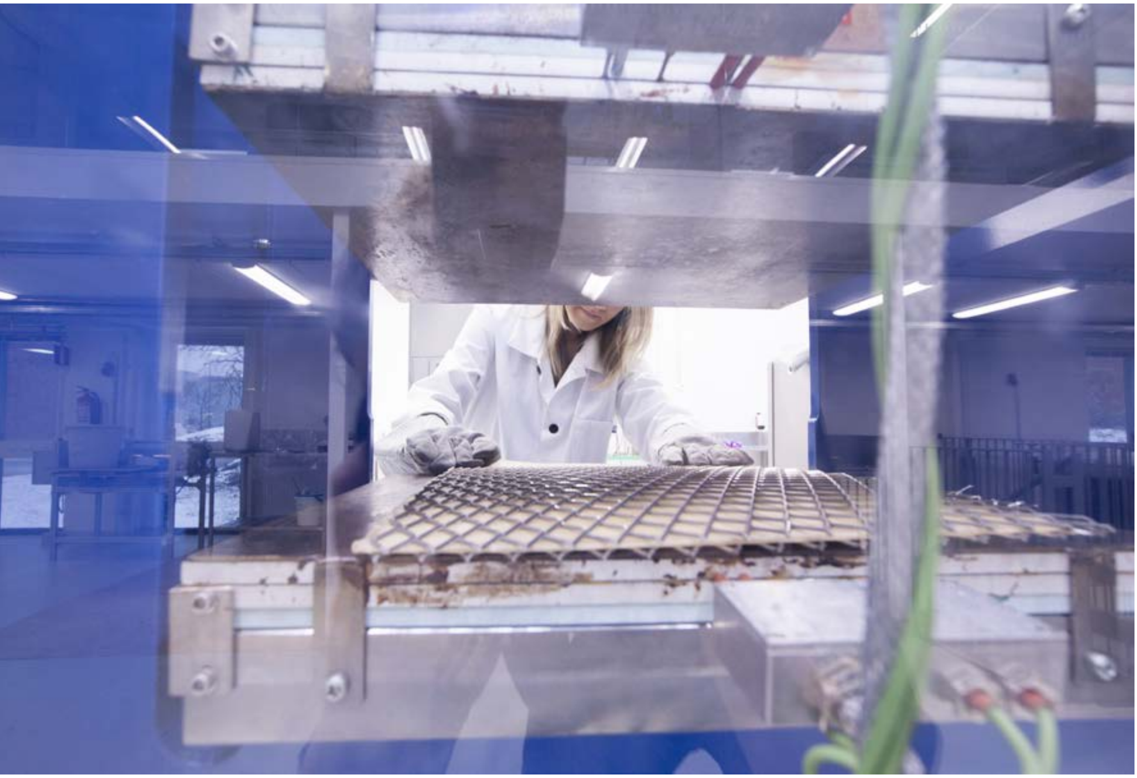
Moulds can be made out of metal, silicone, wood or plaster. Different materials provide different properties. Moulds made out of plaster remove water effectively whereas metal and wooden moulds are durable and can be used with pressure. Silicone's hydrophobicity and elasticity facilitates removing the sample and producing more complex shapes. The material of the mould not only gives shape; it also helps the drying process.

↗ *Moulding pine bark mixed with microfibrillar cellulose.*
→ *Material sheet in a plaster mould.*

PRESSING

Many cellulose-based materials shrink and curl up when they dry. Pressing is a method for controlling shrinkage, preventing curling and adding material density. At its simplest, pressing can be performed using absorbent papers and a weight, a method that is traditionally used for drying flowers. A hydraulic hot press enables controlling both temperature and pressure and drying samples more quickly, which supports efficient material iteration. With a hot press it is possible to change shapes and create composites with thermoplastic properties.

↓ *Pattern experimentation using a hot press.*
→ *Microfibrillar cellulose (MFC).*



COOKING RULES AND SAFETY

Iina Solala

As with any cooking, it is also vitally important to work safely at all times when trying out the CHEMARTS recipes – not just for your own sake but also for the safety of your co-workers and the environment. To work in any professional laboratory, you typically need to complete the safety training organized by the institution in question. Regardless of whether you work at home or at a workshop, you still need to be aware of the safety of the materials and processes you are working with, and to know how to discard leftovers and waste.

The choice of workspace ultimately depends on the level of safety required for the materials you work with. For example, food colours and other ingredients used for nutrition are generally considered safe, and can be worked with at home. The same also applies to wood pulp, microcrystalline cellulose, and cellulose nanofibrils. However, if you work with organic solvents or other chemicals, you have to work in a laboratory-like setting with a fume hood and an established waste management protocol. Most of the CHEMARTS recipes can be followed using standard kitchen equipment (bowls, pans, glasses, heating plates etc.), but you should keep these only for your experiments and not use them for preparing food afterwards.

↓ *Appropriate protective equipment: laboratory coat, safety goggles, protective gloves and a mask.*

NEVER EAT OR DRINK ANYTHING IN YOUR WORKING AREA or during your experiments! Even if you only work with food ingredients, treat them as chemicals and do not eat them. This ensures you do not accidentally ingest anything harmful.

USE APPROPRIATE PROTECTIVE EQUIPMENT: an apron, a laboratory coat, safety goggles, and protective gloves (e.g. nitrile rubber gloves). If you have long hair, you should tie it back.

FAMILIARIZE YOURSELF WITH THE SAFETY INFORMATION related to all the ingredients. Material safety data sheets (MSDS) are available online for all chemicals. You can find these by searching, for example, 'acetone MSDS'. MSDS list the different risk factors related to the chemical in question and provide instructions on the required protective equipment and first aid measures.

READ ALL INSTRUCTIONS CAREFULLY BEFOREHAND, including information on chemical safety. Know what you are doing, and do not hesitate to take time to think if you are unsure of how to proceed. Be aware of hot water and steam when cooking, and be extra careful when working with flammable solvents (e.g. acetone, ethanol). Move carefully when carrying any chemicals and learn what to do in the case of an accident, including chemical spillage or fire. If you are exposed to a chemical, administer first aid according to the instructions listed in the MSDS and seek medical help. Inform the attending physician of any chemical exposure.

MARK YOUR SAMPLES (including sample type, your name, date, and contact information), and document your experiments properly by writing down all recipes and sample descriptions, as well as taking photos or videos. This will make it possible to reproduce your work and allow others to assess how to handle your samples safely.

AFTER THE EXPERIMENTS: wash your glassware and utensils, clean up, dispose of waste, and put everything in its right place. Finally, wash your hands before leaving the working area.


80
60
40

3
RECIPES

HARD

Wood can be used as a solid material, or as particles obtained through either mechanical or chemical processing. Some tree species are very hard (like oak) and others are soft (like spruce). Solid wood is often processed using traditional techniques such as sawing, carving and milling. The sawdust and wood flour from these processes are used for composites, and today they are often mixed with thermoformable resins such as certain plastics or PLA for easy moulding and water repellency.

A common approach in CHEMARTS experiments to producing hard materials is to use microfibrillar cellulose (MFC) together with fillers such as bast fibres, pulp, sawdust, flour, plaster, or earth. Removing the water from the mixture forms bridges between the filler particles, which restrict the shrinkage of the formed shape during drying. Cellulose derivatives such as CMC (solution in water) or cellulose diacetate (solution in acetone) may replace MFC as the binder. Using nanofibrillar cellulose (NFC) to make hard, tailored shapes is demanding because of its high water content and huge drying shrinkage. In this case, drying in plaster moulds can offer a solution. However, as the water resistance of these cellulose-based materials is usually not very good, the first real-life applications should be tested in areas in which water resistance is not essential.

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HARD

1 CELLULOSE TUBES

Tapani Vuorinen, CHEMARTS *2018*

Hard, light structures with a three dimensional shape can be created by drying wet microfibrillar cellulose (MFC) on a mould or other 3D structure. By adding pulp fibres, you can prevent ruptures during the drying process and improve the material's properties. This recipe demonstrates how you can make tubular shapes (e.g. 6 cm long tube with a 4 cm diameter), but it can also be applied to create various other shapes.

INGREDIENTS

100 ml Water
200 g Microfibrillar cellulose (MFC), DMC 3%
3 g Dry pulp (e.g. pulp sheet or tissue paper)

EQUIPMENT

Scales
Bowl
Hand blender
Filtration fabric bag
Tubular mould

METHOD

1. Measure the water into a bowl.
2. Shred the dry pulp into small pieces and soak them in water for a few minutes or more.
3. Mix using a hand blender until the pulp is dispersed evenly.
4. Add the MFC to the bowl and continue mixing using a hand blender.
5. Remove any excess water by putting the material inside a filtration fabric bag and pressing.
6. Spread the mass onto a tubular mould as a layer of 5 mm or thicker.
7. Dry in an oven at 50–80 °C overnight or for several days at room temperature.

♥ **TIP** Select a fabric with a mesh count high enough to hold in the mixture and allow water to pass through.

♥ **TIP** Microfibrillar cellulose shrinks while drying and creates high pressure on the mould. Select a shape or tube that keeps its shape under compression, and allows the sample to be removed without damaging either it or the mould. For example, a piece of rubber or plastic hose makes a good mould.

A tubular mould with two parts, a hard inner part to hold the shape and a softer outer part that enables the removal of the inner part first and then the sample after drying.

HARD

2 PINE BARK REINVENTED

Aarni Tujula, CHEMARTS *Summer School 2019*

Mixing the powder of pine bark, a forestry residue and microfibrillar cellulose, creates a new all-wood material. The material resembles nature in its smell, feel and appearance. The end result is light and durable and can be made into either sheets or 3D objects.

INGREDIENTS

10 g Pine bark
100 g Microfibrillar cellulose (MFC), DMC 3%
(250 ml Water)

EQUIPMENT

Knife
Grinding mill or mortar
Scales
Bowl and a spoon

For creating sheets:
Nylon or polyester filtration fabric
Absorbent papers
Hot press or a weight

For creating 3D shapes:
Plaster mould

METHOD

1. Cut dry pine bark into small pieces with a knife and grind the pieces into a fine powder with a grinding mill or mortar.
2. Measure the MFC and pine bark powder into a bowl and mix.

✱ **SAFETY** Wear a mask when grinding bark with a grinding mill.

➜ TO CREATE A SHEET:
Spread the mixture as a 5–10 mm layer on top of a piece of filtration fabric. Lay another piece of fabric on top of the material layer. Place the sample with fabrics between some absorbent papers to remove excess water. Dry the sample underneath a weight for several days or use a hot press. With a hot press you will get dry samples in ca. 40 min at 80 °C. Changing the absorbent papers during the process will speed up the drying.

➜ TO CREATE SHAPES WITH A PLASTER MOULD:
Add 250 ml of water until the mixture becomes fluid. Fill the mould with the mixture. Solid material will start to condense on the walls of the mould when the plaster removes the water. Keep adding the mixture into the mould to keep it full. After one minute, pour any excess mixture back into the bowl. Wait until the sample detaches from the walls or until it is dry before removing it from the mould. Drying might take several days.

♥ **TIP** Select a filtration fabric with a mesh count high enough to hold in the mixture and allow water to pass through.
♥ **TIP** You can vary this recipe by testing different tree barks or other kinds of finely ground materials from nature.

HARD

3 FIBRE BOWL

Tapani Vuorinen, CHEMARTS *2018*

Thin, light materials can be produced by combining long natural fibres with microfibrillar cellulose (MFC). The choice of fibres influences the appearance of the object: its colour, texture and feel. In this recipe, flax provides a long fibre reinforcement and gives the bowl a silvery shade.

INGREDIENTS

150 g	*Microfibrillar cellulose (MFC), DMC 3%*
3 g	*Bast fibres (flax, hemp, jute, etc.)*

EQUIPMENT

Scales
Mixing bowl and spoon
An object to create the bowl shape
(Oven)

METHOD

1. Measure the MFC into a bowl.
2. Add the fibres and mix well.
3. Spread a ca. 5 mm layer of the mixture onto an object, for example a bowl turned upside down.
4. Dry in an oven at 100 °C for 2 hours, at 40–80 °C overnight, or for several days at room temperature. Note: if you use an oven for drying, the object you use for shaping needs to be heat-resistant glass, ceramic, metal or silicone.

♥ **TIP** It is difficult to mix long fibres evenly – cutting the fibres with scissors, for example to 5 mm, makes it easier to get an even mixture.

♥ **TIP** You can produce fibres of your own from nature. See how on page 122.

HARD

4 COMMON REED PANELS

Päivi Lehtinen, CHEMARTS *Summer School 2017*

Common reed grows on waterfronts and has traditionally been used in, for example, roofs and carpets. Common reed is water-repellent, grows quickly and in some cases, can take over shallow lakes and needs to be torn away. This recipe shows a way to simply glue together common reed panels using pulp. The panels become quite strong but are not water-resistant.

INGREDIENTS

Bunch of common reed straws

40 g	*Unbleached pulp (dry) or recycled brown cardboard*
1.4 l	*Water*
1 ml	*Dishwashing liquid*

EQUIPMENT

Band saw or other cutter
Bowl
Scales
Hand blender
Filtration fabric bag
Metallic net or silkscreen
Tightenable support collar

METHOD

1. Cut the common reed straws into 4 cm pieces using a band saw or other cutter (length depends on how thick you want the material to be).
2. Measure the water into a bowl.
3. Shred the pulp into small pieces and add them to the water. Let them soak until the texture becomes soft.
4. Mix using a hand blender until the pulp is dispersed evenly.
5. Add dishwashing liquid and mix to create a gel-like mixture.
6. Remove any excess water by placing the mixture in a filtration fabric bag and pressing using your hands. The mass should be wet but not dripping.
7. Spread the pulp mixture onto a piece of fabric in a thin layer measuring about 4 × 10 cm.
8. Place the cut straws in a row on top of the pulp layer.
9. Spread another layer of pulp on top of the straws.
10. Roll the sheet up using the fabric.
11. Take the roll from the fabric and place it upright onto a metal net or silkscreen so that air can flow freely underneath it.
12. Make more rolls and place them upright side by side to create a bigger panel.
13. Place a collar around the panel and tighten it. Squeeze out any excess water.
14. Dry in an oven at 50–80 °C for several days, or at room temperature for days or weeks. Tighten the collar during the drying process as often as needed.

Two panels and a furniture leg made from common reed straws.

HARD

5 HOBBY CLAY FROM CELLULOSE

Nina Riutta, CHEMARTS *2019*

With this recipe you can produce your own bio-based hobby clay from microfibrillar cellulose (MFC) and starch. This safe, all-natural dough can be used to create simple figurines or for other crafts. You can colour it using natural pigments.

INGREDIENTS

50 g	*Microfibrillar cellulose (MFC), DMC 3%*
7 g	*Corn starch*
ca. 1 g	*Turmeric or other organic pigment*

EQUIPMENT

Scales
Bowl
Filtration bag
(Oven)

METHOD

1. Measure the MFC into a filtration bag. Remove 20 ml of water by pressing.
2. Move the MFC into a bowl. Add the corn starch and knead by hand. If the mixture is too dry for a hobby clay, add more MFC. If it feels too wet, add more starch.
3. Mix in pigment if you want to colour the dough.
4. Use the dough for your creation.
5. Dry the figurines in an oven at 40–60 °C for several hours or at room temperature for a few days, depending on the thickness of the objects.

♥ **TIP** Old figurines can be reused later to some extent: soften the figurines with a small amount of water, knead, and roll into a new dough.
♥ **TIP** If the mass using coloured with biodegradable pigments, items can be composted or recycled in a bio-bin.

✸ **SAFETY** When using pigment powders, wear a mask and protect yourself and your surroundings from staining.

→ *Uncoloured and coloured pieces of hobby clay. Pigments used: Red Lake C and Indigo blue.*

HARD

6 LIGHT PLASTER WITH CELLULOSE

Nina Riutta, CHEMARTS 2019

Microfibrillar cellulose (MFC) mixed with gypsum powder creates light composites. The gypsum helps minimize shrinkage and allows control over shape. MFC bonds with gypsum and enables notably lighter structures than plaster on its own.

INGREDIENTS

100 g Microfibrillar cellulose (MFC)
50 g Gypsum

EQUIPMENT

Scales
Bowl and spoon
Mould or drying surface
(Oven)

METHOD

1. Measure the MFC into a bowl.
2. Add the plaster and mix well using a spoon.
3. Pour the mixture into a mould or spread onto a surface.
4. Dry at room temperature or in an oven at a maximum of 40 °C for one or more days depending on the sample thickness.

SAFETY Plaster can cause irritation to the respiratory system so always wear a mask when working with it in powder form. Handle it carefully and avoid dusting it.

TIP Do a test series to see how the properties change when you vary the mixing ratio of MFC and plaster.

HARD

7 SHAPING SAWDUST

CHEMARTS *team 2016*

The forest industry creates various residues and byproducts, for example trimmings, branches, stumps, bark, and sawdust. Utilizing these residues supports system circularity. This recipe shows how wood powder together with another wood-based material, in this case microcrystalline cellulose (MCC), creates a new material mixture that can be moulded into various shapes.

INGREDIENTS

200 g Microcrystalline cellulose (MCC), DMC 16%
20 g Fine wood powder

EQUIPMENT

Scales
Grinding mill
Bowl and spoon
Mould
(Oven)

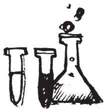
METHOD

1. Grind some sawdust into fine wood powder using a Wiley mill or other suitable device.
2. Measure the MCC and fine sawdust into a bowl and mix well.
3. Select a mould with your desired shape, and fill it with the mixture.
4. Dry in an oven at 40–60 °C overnight or at room temperature for several days, depending on the sample thickness.

SAFETY Wear a mask when grinding wood with a grinding mill.

TIP Try replacing the wood powder with powder of other by-products or residues from forestry or agriculture.
TIP You can experiment with other cellulose-based materials instead of MCC, for example, with carboxymethyl cellulose (CMC).
TIP If you want to design a shape of your own, it is relatively easy to produce custom shaped moulds from plaster or silicone.

HARD



8 CASTABLE BIO-PEARLS

Iines Jakovlev, CHEMARTS *2017*

Solid forms can also be created from cellulose acetate using other materials as fillers. This recipe introduces the creation of lightweight jewellery with intriguing sensorial properties. The original pearls were decorated with flower petals, blueberry powder, plants, saw dust, silver and gold. Be creative and develop this recipe further!

INGREDIENTS

50 ml *Acetone*
5 g *Cellulose diacetate (CDA) powder*
20 g *Starch (potato or corn flour)*

EQUIPMENT

Fume hood
Laboratory glass bottle with cap
Magnetic stirrer and magnet
Scales
Polyethylene (PE) plastic zipper bag
Syringe
Scissors
Silicone mould

METHOD

➡ TO PREPARE THE 5% CDA SOLUTION IN ACETONE

✱ **SAFETY** When working with cellulose acetate, always use a fume hood, as acetone is volatile.

1. In a fume hood, measure the acetone into a laboratory glass bottle and place a magnet in it.
2. Start stirring with a magnetic stirrer and slowly add CDA.
3. Close the bottle and make sure that the magnet rotates evenly without touching the walls.
4. Cellulose acetate takes about four hours to dissolve. You can use the solution when it is homogenous.

➡ TO CREATE A PEARL

5. Measure the potato starch into a small plastic zipper bag.
6. Add the CDA as 10% solution in acetone to the contents of the bag, using a syringe.
7. Squeeze the air out and seal the bag.
8. Homogenize the mixture by kneading the bag in your hands.
9. To create a pearl, cut open a corner of the bag using scissors and extrude the viscous mixture into a pearl-shaped silicone mould. Start the extrusion from the bottom to avoid the creation of air bubbles.
10. Let the acetone evaporate in the fume hood at least overnight. The pearls can be removed from the mould when the acetone has evaporated.

♥ **TIP** Experiment by adding pigments or other natural ingredients to the mixture, or decorate the pearls with materials from nature. You can use the CDA solution as a glue or as a transparent coating.

SOFT

Textiles (woven, knitted or non-woven) are the most common soft and flexible materials. They are usually produced from long fibres; either natural, such as cotton or wool, or synthetic, such as fossil-based polyester. Man-made textile fibres can also be produced from cellulosic materials such as wood, bamboo or even cow manure (which also contains cellulose) by dissolving the cellulose chemically, and then regenerating the molecular structure in the next production phase. Viscose (also called rayon), lyocell (e.g. Tencel by Lenzing) and modal are the most common existing production methods for man-made cellulose fibres. In recent years, several new fibre production technologies have been invented: for example Ioncell and Spinnova in Finland. However, in this book we do not focus on traditional textile materials or production technologies – we explore experimental techniques for producing thick or thin, or soft or flexible materials from cellulose and other natural materials.

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Reinforced pulp foam by Tomi Jeskanen, 2019.

9 PULP FOAMS

CHEMARTS *team 2017*

Foaming is a way of adding air to materials and increasing their bulkiness and softness. Using surfactants promotes the mixing of air in polymer solutions or suspensions of solid particles. Following these principles, it is easy to produce light foams of pulp fibres (virgin or recycled), microcrystalline cellulose or water-soluble cellulose derivatives. Foamed pulp can potentially be used to make products that are affordable, recyclable or disposable.

INGREDIENTS

5 g	*Paper pulp (from pulp sheets or paper)*
100 ml	*Water*
1 ml	*Dishwashing liquid*

In workshop or laboratory conditions, other foaming agents can be used instead of dishwashing liquid; for example, 0.1 g of sodium dodecyl sulphate (SDS).

EQUIPMENT

Scales
Bowl and spoon
Hand blender with beater blade
Drying surface
Container for dripping water
(Oven)

METHOD

1. Measure the water into a bowl.
2. Shred the pulp or paper into small pieces and add them to the water. Let them soak for at least a few minutes.
3. Mix using a hand blender until the pulp is evenly dispersed.
4. Add dishwashing liquid and mix using the hand blender (using a beater blade) until the foam is even.
5. Spread onto a surface for drying. Select a surface on which the water can drain away. Place a container underneath to catch the dripping water.
6. Dry in an oven at 40–60 °C overnight or at room temperature for several days.

♥ **TIP** Paper is harder to disperse than virgin pulp, and you may need to soak it overnight before Step 3.
♥ **TIP** Dry your foam on top of a silkscreen for example – the water drips through the net. To create shapes you can use moulds with small water exits.

10 SOFT SPONGE

Jui-Fan Yang, CHEMARTS *Summer School 2019*

In this recipe, foaming creates light, soft, sponge-like materials that break easily with water. Because the material breaks in water and its degradation is fast, it is a great option for disposable products. The recipe's main ingredient, microcrystalline cellulose (MCC) was produced using AaltoCell™ technology. This new technology uses significantly less chemicals and saves energy, making the raw material affordable and production greener.

INGREDIENTS

9 g	*Pulp (Sheets, tissue paper)*
300 ml	*Water*
100 g	*Microcrystalline cellulose (MCC), DMC 10%*
20 ml	*Carboxymethyl cellulose (CMC), medium viscosity, 3% solution in water*
20 ml	*Glycerol*
3 ml	*Dishwashing liquid*

EQUIPMENT

Scales
Hand blender
Bowl
Mould
(Oven)

➜ TO PRE–PREPARE 100 ML OF 3% CMC SOLUTION IN WATER

1. Add 3 g of CMC powder to 100 ml of cold water and mix with a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 20 ml of the solution, store the rest for later use.

METHOD

1. To ensure an even mixture, add the pulp to the water and let it soak for at least a few minutes.
2. Disperse the pulp fibres well using a hand blender.
3. Drain away 250 ml of water using filtration fabric.
4. Add MCC, CMC solution, glycerol, and dishwashing liquid, and mix using a hand blender until the foam is even.
5. Pour the foamed mixture into a non-stick mould.
6. Dry in an oven at 40–60 °C overnight or at room temperature for several days.

♥ **TIP** You can colour the mixture using liquid dyes by mixing the colour with glycerol first.

♥ **TIP** To create custom-shaped sponges, you can create your own mould from silicone, for example.

SOFT

11 SOLID FOAM

Tapani Vuorinen & Tomi Jeskanen, CHEMARTS *team 2019*

Solid, light foams can be created from methyl cellulose (MC). When a liquid foam of methyl cellulose is heated it solidifies and retains its dimensions. This feature makes it possible to produce various shapes in an oven using a mould. Imagine if in the future, fossil-based packaging styrofoam was replaced by this bio-based foam!

INGREDIENTS

6 g Methyl cellulose (MC), high viscosity
200 ml Water
0.1 g Sodium dodecyl sulphate (SDS)

EQUIPMENT

Scales
Magnetic hot plate stirrer and magnet
Beaker
Bowl and mixing spoon
(Refrigerator)
Hand blender
Mould or tray
Oven

METHOD

➜ TO PREPARE 3% MC SOLUTION IN WATER

1. Measure the water into a beaker and heat on a magnetic hot plate stirrer to at least 80 °C while stirring.
2. Slowly add the MC.
3. Switch the heating off and continue the stirring until the mixture cools down. The white powder remains visible.
4. Let the mixture stand overnight at room temperature or in a refrigerator (don't place the hot mixture directly into a refrigerator). After complete dissolution, the mixture is a clear, viscous solution.

➜ NEXT DAY

5. Move the solution into a bowl.
6. Add the SDS and mix using a hand blender with a beater blade until the foam is even.
7. Place the foam into a mould or spread as a layer on a tray.
8. Dry in an oven at 80 °C to solidify. Remove from the oven when the sample is dry and firm.

✸ **SAFETY** When creating shapes, choose a mould material that can withstand heat. For example glass, metals, ceramic and silicone resistant to heat.

→ *Samples of foamed methyl cellulose (MC) and pulp by Luisa Jannuzzi, 2019.*


MC8
15MC
MC 1

FLEXIBLE

When layers of wet pulp or other cellulose-based materials dry, they tend to form stiff structures. Although stiffness is an advantage in several applications, being able to broaden the material property spectrum towards more flexible leather-like or stretchable rubber band behavior would offer more possibilities for replacing existing materials with more sustainable cellulose-based alternatives.

A general solution to reduce the stiffness of cellulosic materials is to apply additives that restrict bond formation during drying or increase the moisture content of the material under normal air humidity. For example, adding glycerol, or calcium chloride can bring flexibility to various cellulose-based materials.

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12 CELLULOSE LEATHER

Jui-Fan Yang, CHEMARTS *Summer School 2019*

Cellulose leather is flexible and feels firm and leather-like, providing a plant-based alternative for applications that can be produced from bendy sheets. The water resistance of the material can be improved by adding a coating.

INGREDIENTS

100 ml	*Water*
5 g	*Pulp*
130 g	*Microcrystalline cellulose (MCC), DMC 10%*
30 ml	*Carboxymethyl cellulose (CMC), medium viscosity, 3% solution in water*
35 ml	*Glycerol*
20 g	*Corn starch*
5 ml	*Vinegar*

EQUIPMENT

Scales
Bowl
Hand blender
Pan and stove
Mould or tray
(Oven)

➡ TO PRE-PREPARE 100 ML OF 3% CMC SOLUTION IN WATER

1. Add 3 g of CMC powder to 100 ml of cold water and mix with a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 30 ml of the solution. Store the rest for later use.

METHOD

1\. Measure the water into a bowl. Shred the dry pulp into small pieces and add to the water. Let the pulp shreds soak at least for a few minutes. Mix using a hand blender until evenly dispersed.
2\. Move the mixture into a pan.
3\. Add the MCC, CMC solution, glycerol, corn starch and vinegar into the same pan and mix well.
3\. Move the pan onto the stove. Heat slowly, constantly stirring until bubbles start to form.
4\. Spread the solution as a 4–6 mm layer onto a mould or tray.
5\. Dry in an oven at 50–60 °C overnight or for several days at room temperature.

♥ **TIP** Non-stick surfaces or creasing the mould or the tray make detaching the sample easier.

♥ **TIP** You can colour the mixture using liquid dyes by mixing the colour with glycerol first.

FLEXIBLE

13 CELLULOSE MEETS NATURAL RUBBER

Sushant Passi, CHEMARTS *Summer School 2018*

Natural rubber, i.e. caoutchouc, is a natural polymer and collected as latex from rubber trees. This recipe combines natural rubber with microfibrillar cellulose (MFC) and carboxymethyl cellulose (CMC), creating a material that originates 100% from trees. Sheets produced from this material are flexible and firm, and the feel mimics that of leather. The material softens in water. The sample has the distinctive odour of natural rubber.

INGREDIENTS

140 g Microfibrillar cellulose (MFC), DMC 3%
100 ml Carboxymethyl cellulose (CMC), high viscosity, 1% solution in water
30 g Natural rubber latex

EQUIPMENT

Scales
Bowl
Hand blender
Baking paper
Chopping board
Clips/tape
Oven

TO PRE–PREPARE 100 ML OF 1% CMC SOLUTION IN WATER

1. Add 1 g of CMC powder to 100 ml of cold water and mix using a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.

METHOD

1. Measure the MFC, CMC solution and natural rubber latex into a bowl and mix well using a hand blender.
2. Secure some baking paper onto a chopping board with clips or a tape.
3. Pour the mixture onto the baking paper and spread a 3 mm or thicker layer across the sheet.
4. Dry in an oven at 50 °C overnight.

TIP You can intentionally create bubbles while mixing, to add texture to the final result.

TIP For best results, spread to an even thickness.

FLEXIBLE

14 BIO SLIME

Chiao-wen Hsu & Yu Chen, CHEMARTS *Summer School 2019*

Making DIY slimes has become extremely popular in recent years, especially among school children. This bio slime is stretchable, elastic and slightly sticky. It contains no toxic or harmful chemicals. When playing is done, it can be composted or recycled in a bio-bin.

INGREDIENTS

75 ml Water
4 g Microcrystalline cellulose (MCC)
900 ml Carboxymethyl cellulose (CMC), high viscosity, 1% solution in water
100 ml Glycerol

EQUIPMENT

Scales
Bowl and spoon
Hand blender
Plastic tray (size around 20 × 30 cm, depth min. 2 cm)
Oven

➜ TO PRE-PREPARE 900 ML OF 1% CMC SOLUTION IN WATER

1. Add 9 g of CMC powder to 900 ml of cold water and mix using a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.

METHOD

1. Measure the water and dry MCC powder into a bowl and mix well using a hand blender.
2. Add the 1% CMC solution and glycerol and mix well using a spoon (to avoid creating bubbles).
3. Let the solution stand overnight.
4. Pour the solution onto a plastic tray and spread evenly.
5. Dry in an oven at 50 °C for three days until the sample is dry and touching leaves no fingerprints on its surface.
6. Remove the sample from the container, starting from the corners.

♥ **TIP** Air bubbles might reduce the strength of the sample. If bubbles persist, you can allow the CMC solution to stand longer than overnight before use.

15 FLEXIBLE SHEETS USING A CALCIUM CHLORIDE BATH

Tapani Vuorinen, CHEMARTS *2018*

Soft, bendable sheets can be created from nanofibrillar cellulose (NFC) using aqueous calcium chloride ($CaCl_2$) solution. When soaking wet material on a tray in a bath, the sodium ions in the material are exchanged for calcium ions, which additionally bind chloride as counterions. When dried, these ions absorb humidity from the atmosphere and give the material its flexibility. Fibres can be added to make the sheet stronger or change its appearance. Instead of pulp fibres, you can use cut bast fibres or other natural fibres, such as cattail seed fibres.

INGREDIENTS

100 ml Water
1–2 g Fibres (1–20 mm long)
100 g Nanofibrillar cellulose (NFC), DMC 2%

For calcium chloride bath:
20 g calcium chloride per litre of water

EQUIPMENT

Scales
Bowl and spoon
Hand blender
Plastic cutting board
Container for $CaCl_2$ bath
Oven

METHOD

1. Weigh the dry fibres and disintegrate them into water using a hand blender.
2. Add the NFC and mix well using a hand blender.
3. Spread the mixture evenly on a cutting board (2–5 mm layer).

➜ TO PREPARE A $CaCl_2$ BATH
Select a container that is larger than the cutting board. To prepare, for example a 4-litre bath, pour 4 litres of water into a container and add 80 g of $CaCl_2$. Mix with a spoon until the $CaCl_2$ is dissolved.

✸ **NOTE** $CaCl_2$ solution is corrosive to steel. Avoid using steel tools, and if the solution spills onto a steel surface, wash the surface well with water to prevent any formation of rust.

4. Sink the NFC sample, on a cutting board, into the $CaCl_2$ bath for a minimum of one hour. Mix the solution gently every 15 minutes to advance the mass transfer between the bath and the sample. The NFC-fibre layer will detach from the support on its own during the bath treatment.

5. Remove the sample from the bath on the support and tilt it carefully to remove the excess $CaCl_2$ solution from the surface.
6. Dry at 40–60 °C in an oven overnight. If the cutting board is wet, protect the oven from $CaCl_2$ solution with a pulp sheet or newspaper. Monitor the drying process to avoid excessive drying in the oven.

♥ **TIP** The soaking time should be long enough to guarantee the ion exchange throughout the sample. With relatively thin samples (< 5 mm), one hour of soaking generally produces the expected effect. Use longer soaking times for thicker samples.

♥ **TIP** The sheet properties depend on the relative humidity of the air. In low humidity, the samples may lose their flexibility, and in high humidity the samples might start to sweat.

FLEXIBLE

16 NANOCELLULOSE FILM

Jouni Paltakari and his research team, CHEMARTS *team 2019*

Nanocellulose films are being explored as a promising material for science and business, to be used as biodegradable sheets for printed electronics or optical devices, for example. When nanocellulose dries, it shrinks and curls up. With additives, it is possible to control the drying and create firm, translucent sheets.

INGREDIENTS

100 g Nanofibrillar cellulose (NFC), DMC 2%
10 ml Glycerol
200 ml Water

EQUIPMENT

Scales
Magnetic stirrer and magnet
Beaker and spoon
Petri dish with a 15 cm diameter and 2.5 cm in height.
(Oven)

METHOD

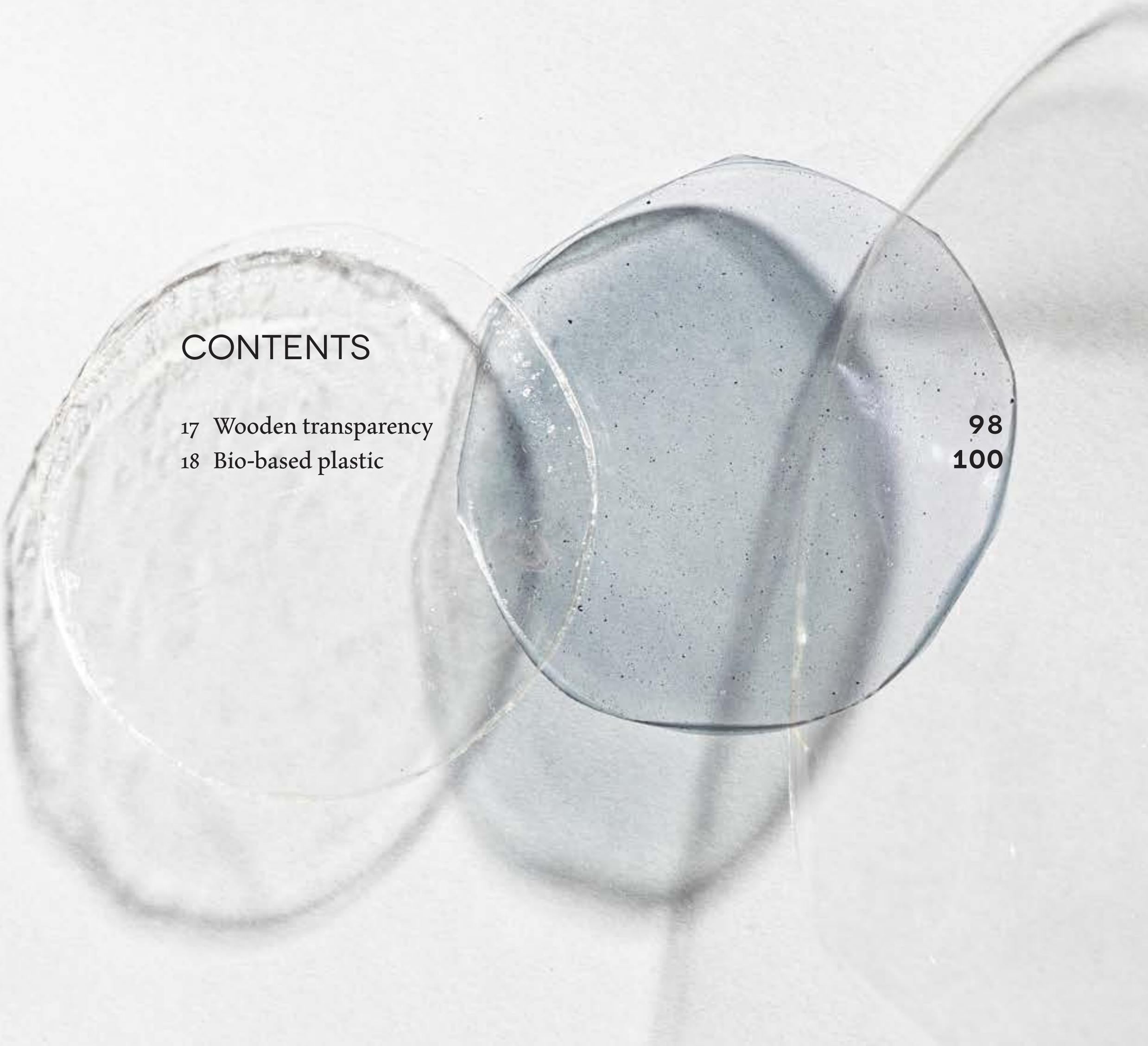
1. Measure the NFC and water into a beaker and mix together using a spoon.
2. Place the magnet into the beaker and move the beaker onto a magnetic stirrer. Turn on the stirrer, making sure that the magnet rotates evenly without touching the sides. Continue mixing for 24 hours.
3. Add the glycerol to the beaker. Mix for 1 hour.
4. Pour the mixture onto a petri dish as a 5 mm or thicker laye.
5. Dry in an oven at 30–40 °C for several days, or at room temperature for days to weeks as needed.

♥ **TIP** You can test replacing glycerol with sorbitol or Polyvinyl Alcohol (PVOH). The upper limit for these additives is 30% of dry weight. When the percentage rises, homogeneity and uneven parts may appear. When using sorbitol or PVOH, cover the petri dish with a filter paper to even out the humidity during drying.

→ *Nanofibrillar cellulose (NFC) films coloured using madder root, willow bark and indigo pigment. Experiments by Nina Riutta, 2019.*

TRANSPARENT

Traditional cellophane is an example of a transparent cellulose-based material. Its production method is quite complicated, and new production methods for similar materials are currently being developed. Other examples are cellulose diacetate (CDA) and triacetate (CTA), which are commonly used in eyewear frames, for example. Although produced from renewable sources, CDA and CTA are plastic-like materials.Nanofibrillar cellulose (NFC) and carboxymethyl cellulose (CMC) can be used to produce transparent films that are biodegradable.



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17 WOODEN TRANSPARENCY

CHEMARTS *team 2019*

This technique uses carboxymethyl cellulose (CMC) to create thin, transparent, water-soluble films that can potentially be used in many concepts. These biodegradable and biocompatible films could replace plastics in some applications. CMC solution needs to be prepared one day in advance.

INGREDIENTS

1 g *Carboxymethyl cellulose (CMC), high viscosity*
100 ml *Water*

EQUIPMENT

Scales
Bowl
Hand blender
Plate or a petri dish
(Oven)

METHOD

➡ TO PREPARE 1% CMC SOLUTION IN WATER

1. Add 1 g of CMC powder to 100 ml of cold water and mix using a hand blender.
2. Let the mixture stand overnight.
3. After complete dissolution, the mixture is a clear, viscous solution.

➡ NEXT DAY

1. Pour the mixture onto a plate, for example a petri dish made from polypropylene or glass, as a 3 mm thick layer.
2. Dry in an oven at a maximum of 80 °C for several hours, or for several days at room temperature.

♥ **TIP** Carboxymethyl cellulose is available in high, medium and low viscosity grades. With medium and low viscosity grades, more concentrated solutions of CMC can be used. Do a test series to see how the viscosity of the solutions and the film properties change when the concentration of CMC is varied in the range of 1–3%.

→ *Carboxymethyl cellulose (CMC) samples coloured using indigo pigment and dyes from flower pedals and rowan. Experiments by Nina Riutta, 2019.*

18 BIO-BASED PLASTIC

CHEMARTS *team 2016*

Cellulose acetates are plastic-like materials made from wood-based raw materials. From acetates it is possible to form transparent, durable materials that are insoluble in water. Cellulose acetates are commercially available and have been used to produce tools and eyewear, for example. In CHEMARTS, cellulose acetates have also been applied as a coating to improve the water resistance of other materials and for applying UV protecting additives from spruce inner bark.

INGREDIENTS

100 ml Acetone
5 g Cellulose diacetate (CDA) powder

EQUIPMENT

Fume hood
Laboratory glass bottle with cap
Magnetic stirrer and magnet
Scales
Petri dish (or similar glassware)

METHOD

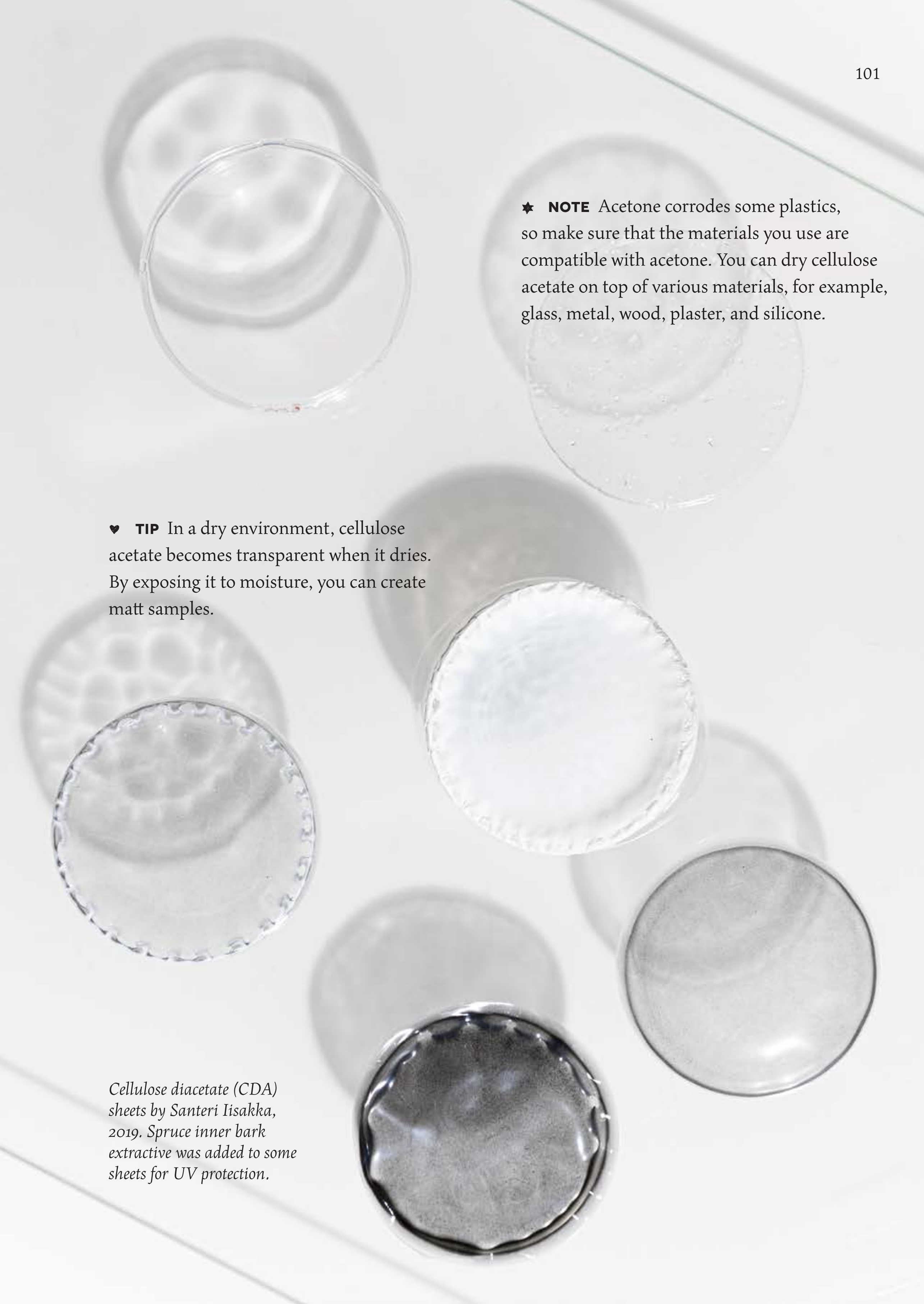
➔ TO PREPARE THE 5% CDA SOLUTION IN ACETONE

✱ **SAFETY** When working with cellulose acetate, always use a fume hood, as acetone is volatile.

1. In a fume hood, measure the acetone into a laboratory glass bottle and place a magnet in it.
2. Start stirring with a magnetic stirrer and slowly add the CDA.
3. Close the bottle and make sure that the magnet rotates evenly without touching the walls.
4. It takes about four hours for cellulose acetate to dissolve. You can use the solution when it is homogenous.

➔ TO CREATE A SHEET

5. Pour a maximum of 10 mm of the CDA solution into a petri dish.
6. Slow down the drying process by placing a loose cover on top of the petri dish. Make sure that there is a small gap for the acetone to evaporate. Without a cover, cellulose acetate dries quickly, forming hollow structures.
7. Drying will take from several days to a week. A transparent sheet forms at the bottom when the acetone has evaporated. Do not detach the sample before it is thoroughly dry. You can remove it easily from the petri dish by soaking in water.



★ **NOTE** Acetone corrodes some plastics, so make sure that the materials you use are compatible with acetone. You can dry cellulose acetate on top of various materials, for example, glass, metal, wood, plaster, and silicone.

♥ **TIP** In a dry environment, cellulose acetate becomes transparent when it dries. By exposing it to moisture, you can create matt samples.

Cellulose diacetate (CDA) sheets by Santeri Iisakka, 2019. Spruce inner bark extractive was added to some sheets for UV protection.

PRINTED MATERIALS

Additive manufacturing, often called 3D printing, involves several technologies, each requiring specific machinery and materials. Cellulose-based materials are typically not thermoformable (with the exception of cellulose acetates), and for filament printing, usually blended with plastics such as PLA. Various extrusion-based production technologies have also been applied to different kinds of cellulose materials. As the drying process of cellulose is challenging to control, the shrinkage process must be taken into account already in the digital modelling. In this book we share recipes that form experimental 3D shapes by combining materials and letting the drying process create its own shapes.

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19 3D SHAPES THROUGH FREE DRYING

Megan McGlynn, CHEMARTS *Summer School 2019*

This recipe focuses on shrinkage as an intrinsic result of drying cellulose materials. Encasing geometric tessellations between layers of cellulose creates tension in specific directions during the drying process. The resulting shapes are self-formed curvatures that vary widely, depending on the different patterns encased, the amount of material, and the drying conditions. Many of the outcomes are surprising in their strength, beauty and peculiarity.

INGREDIENTS

3D printing filament of Polylactic Acid (PLA)
Microfibrillar cellulose (MFC), DMC 3%

EQUIPMENT

3D printer
Silkscreen (180–280 thread count)
(Oven)

METHOD

1. Design a custom tessellation pattern using vector graphics software and extrude the pattern in 3D modelling software to 0.5 mm thickness.
2. 3D print the pattern using a PLA filament.
3. Spread a 2 mm layer of MFC onto a silkscreen to match the size of the printed pattern. The silkscreen enables the air to flow freely underneath.
4. Gently place the pattern onto the MFC.
5. Spread a second 2 mm layer of MFC to entirely cover the pattern.
6. Dry for 24 hours in an oven at 30 °C or for several days at room temperature.

♥ **TIP** The optimal width of lines in your pattern depends on the 3D printer you use. Do several small tests before printing larger patterns.

♥ **TIP** Uniform layers of MFC create more consistent results and reduce the risk of breakage. You can use guides to make even layers: select 2 mm thick pieces of wood, or 3D print frames that are slightly larger than your pattern.

20 PATTERNING CELLULOSE

Iines Jakovlev 2018, CHEMARTS *2019*

With this extrudable material, it is possible to create custom, light, lace-like patterns and structures. The material can be extruded for use in various applications, for example, for creating accessories, or in art installations. You can find inspiration for patterns or applications using biomimicry.

INGREDIENTS

100 ml	*Water*
1 g	*Pulp*
40 g	*Microfibrillar cellulose (MFC), DMC 3%*
10 ml	*Carboxymethyl cellulose (CMC), medium viscosity, 1% solution in water*

EQUIPMENT

Scales
Bowl and spoon
Hand blender
Filtration fabric bag
Nylon or polyester filtration fabric
Syringe
Nylon or polyester filtration fabric
Absorbent paper
Light metal sheet

➡ TO PRE-PREPARE 100 ML OF 1% CMC SOLUTION IN WATER

1. Add 1 g of CMC powder to 100 ml of cold water and mix using a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 10 ml of the solution. Store the rest for later use.

METHOD

1. Measure the water into a bowl.
2. Add pulp and mix using a hand blender until the fibres are evenly dispersed.
3. Mix in the MFC.
4. Remove any excess water by placing the mixture in a filtration fabric bag and pressing. The mass should be wet but not dripping.
5. Place the mixture into a bowl and mix in the CMC.
6. Scoop the mixture into a syringe with a spoon and avoid creating air bubbles.
7. Place some nylon fabric on top of an absorbent paper. The fabric prevents attachment and the paper removes moisture from the material.
8. Extrude 2D patterns onto the fabric.
9. Dry at room temperature for one day. The shapes shrink and warp when the material dries. If you want to control warping, place a light metal sheet on top of the pattern when it is half dry.

♥ **TIP** For an alternative way of mixing the fibres into the water is to put them into a closed jar and shake vigorously.

♥ **TIP** Create flowers, for example, by making thin petals and gluing them together using the mass.

COLOURING AND DYEING

Before the industrial revolution, only natural dyes and pigments were used as colorants. Today, synthetic dyes have replaced almost all traditional dyes due to their stability, availability and durability. Natural dyes and pigments are becoming fashionable again, but in using them we need to accept two things: natural colours change with time, and we can't keep foraging our precious nature for plants on a larger scale. For example, the bright green of plants comes from chlorophyll and fades very quickly. Some rare lichen provides beautiful reddish hues but takes decades to grow – so we should leave it in peace. Pigments from agriculture or forestry side streams or dyes produced by microbes in laboratories might be a sustainable solution for the future. Sometimes the easiest way to colour your samples is to use commercial food colours or, for example, textile dyes or earth pigments from art stores. You can also look into how inks can be produced from nature.

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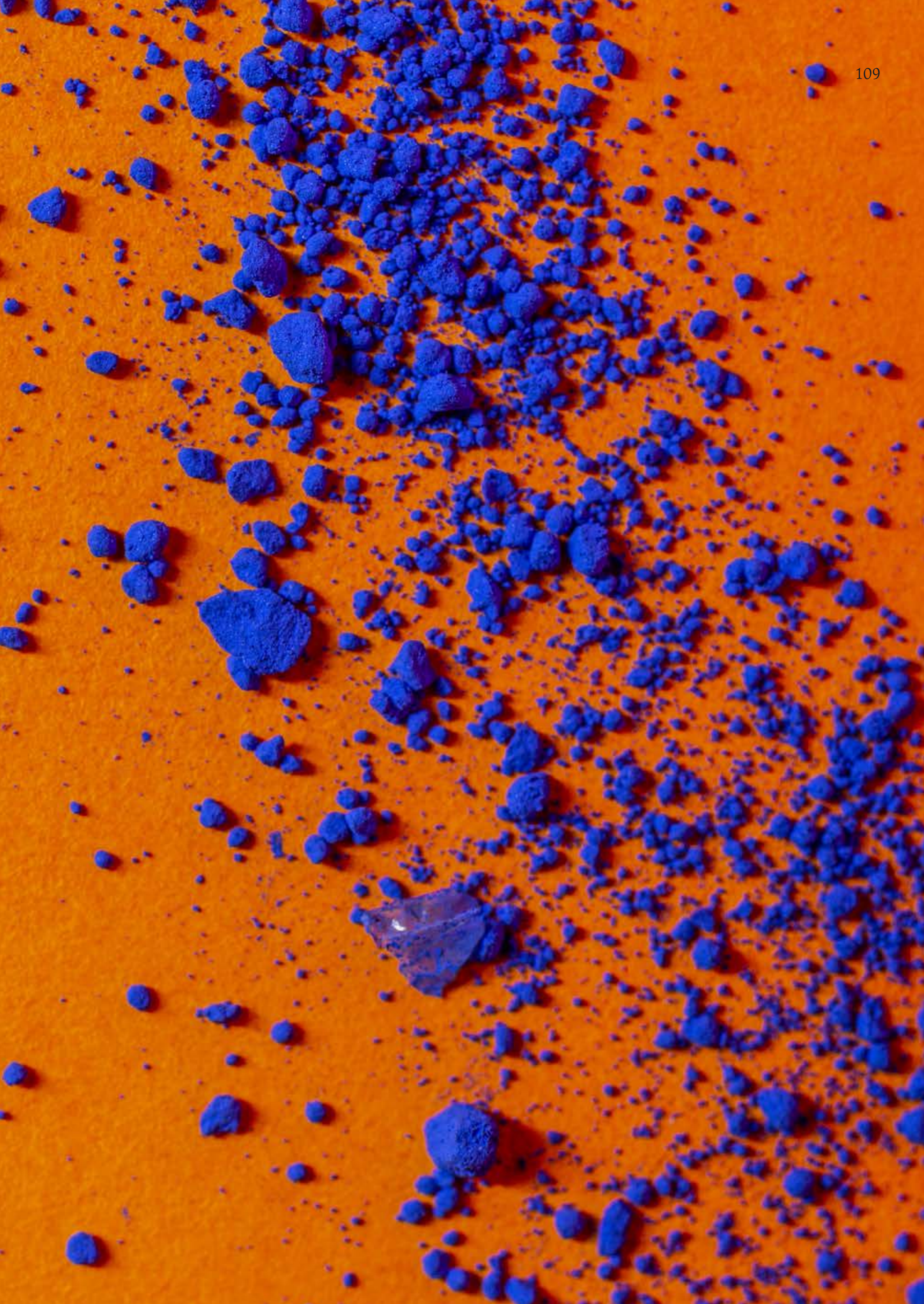


21 DYES FROM NATURE

Aleksandra Hellberg & Jenny Hytönen, CHEMARTS *2019*

Natural dyes can be easily extracted from plants by boiling them in water. The textile materials most suitable for dyeing are protein-based silk and wool, cotton (cellulose) or man-made cellulosic materials such as viscose (also called rayon), lyocell or modal. Only a few fossil-based, synthetic materials such as nylon (polyamide) can be dyed using natural dyes. Before the dyeing process, the materials need to be pre-treated with mordants for deeper shades and increased colour-fastness. You can easily find more information on natural dying; this recipe is based on the book *Dyes from Nature* (Räisänen, Primetta, Niinimäki, 2016).

INGREDIENTS

For pre-treatment of materials

100 g *Yarns of fabric*
2–5 l *Lukewarm water*
10 g *Alum*

For dyeing

Water
100 g *Pre-treated textiles*
1 kg *Fresh plants or*
100 g dried plants

EQUIPMENT

Large pan
Thermometer
Bucket or large bowl

➜ FOR PRE–TREATMENT WITH MORDANTS

1. To achieve even results, soak the materials in lukewarm water in a bucket or large bowl until they are thoroughly wet. Press the excess water out gently.
2. Pour the water into a pan and add the alum. Mix until the alum dissolves.
3. Move the soaked materials from the bucket into the pan and slowly heat the solution to 80 °C.
4. Maintain the temperature for an hour. Don't allow the solution to boil.
5. Allow the solution to cool and hang the materials to dry or place them directly into a dye bath.

♥ **TIP** Some plants, such as willow, can act as natural mordants and no separate pre-treatment is needed.

The recipe continues on the next page.

→ *Yarns dyed using colours from Finnish nature by Iines Jakovlev, 2019.*


Willow leaves
Willow bark 2019
WILLOW BARK

METHOD FOR DYEING

1. Cut the plants into small pieces using scissors or a knife.
2. Place the plant mass into a large pan and add enough water to cover it.
3. Slowly heat until the temperature is about 80 °C. If you use delicate plants such as flowers, the temperature might be lower (50–80 °C). Very hard materials such as cones or branches can be boiled.
4. Maintain the temperature for at least an hour.
5. Strain the dye from the plant mass and add water to the dye if needed; the ratio should be 2–5 litres of dye to 100 grams of textile.
6. Place the pre-treated and well-soaked textiles into the dye bath.
7. Slowly heat the pan to the same temperature as you used when cooking the dye bath.
8. Maintain the temperature for at least an hour. Stir the mixture a couple of times, very carefully, to ensure an even colour.
9. After an hour, let the pan cool down and remove the textiles from the dye bath. Rinse them in a bucket or running cold water until no more colour emerges and the water becomes clear.

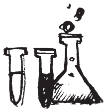
♥ **TIP** Instead of steps 7. and 8., you can test a cold dye bath: place the pre-treated, well-soaked materials in a cooled dye bath and leave them for a day or even longer. Stir occasionally.

♥ **TIP** You can use your dye bath a second time, but the shades will be lighter.

♥ **TIP** Compost the plant mass after cooking, or use it for your material experiments.

♥ **TIP** You can also try dyeing pulp: place minced, well-soaked pulp loosely into a filtration fabric bag, close the bag tightly and place it in a dye bath. Use either a low temperature (50–80 °C) or a cold dye bath.

→ *Sample book by Aleksandra Hellberg and Jenny Hytönen.*



22 NON-ACRYLIC PAINT

Jenni Heikkinen, Mandi Huuki, Zuika Owada, Viktorija Piaulokaite, Lauri Tossavainen & Aino Vaarno
CHEMARTS *Design Meets Biomaterials 2018*

In this recipe, three different cellulose based components – nanofibrillar cellulose (NFC), hydroxypropyl cellulose (HPC) and carboxymethyl cellulose (CMC) – are used to create a biodegradable paint that could substitute acrylic paints.

INGREDIENTS

40 g *Nanofibrillar cellulose (NFC), DMC 2%*
15 ml *Hydroxypropyl cellulose (HPC), 5% solution in water*
15 ml *Carboxymethyl cellulose (CMC), medium viscosity, 3% solution in water*
10 ml *Glycerol*
20 g *Pigment*
(Water)

EQUIPMENT

Scales
Bowl and spoon
Stove and pan

➜ TO PRE-PREPARE 100 ML OF 3% CMC SOLUTION IN WATER

1. Add 3 g of CMC powder to 100 ml of cold water and mix using a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 15 ml of the solution. Store the rest for later use.

➜ TO PRE-PREPARE 100 ML OF 5% HPC SOLUTION IN WATER

1. Add 5 g of HPC powder to 100 ml of cold water and mix using a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 15 ml of the solution. Store the rest for later use.

METHOD

1. Measure the NFC, HPC and CMC into a bowl and mix well.
2. Move the mixture into a pan and heat slowly on a stove. Stir constantly.
3. When the texture is smooth and thick, remove it from the stove.
4. Let the mixture cool slightly and add the glycerol.
5. Add the pigment for the colour, and mix.
6. If the composition seems too thick, add a few drops of water.

♥ **TIP** You can use a magnetic hot plate stirrer instead of a stove to heat and mix at the same time. When using a magnetic mixer, use a glass beaker instead of a pan.

23 PAINTING WITH NANOCELLULOSE GEL

CHEMARTS *team 2015*

Nanofibrillar cellulose (NFC) resembles jelly, making it an inspiring material for creative experiments. When coloured with food colorants, NFC paints are non-toxic, water soluble and a safe choice for children. The colours might look delicious, but do not eat them!

INGREDIENTS FOR ONE COLOUR

0.5 dl Nanofibrillar cellulose (NFC), 2 % DMC
0.5 dl Water
Some drops of food colour

EQUIPMENT

Small bowls and spoons
Brushes
Thick aquarelle paper

METHOD FOR ONE COLOUR

1. Mix the NFC and water in a bowl.
2. Add a few drops of food colour and mix well using a spoon. Test the colour on a paper with a brush and add more colour if needed.
3. Add water if the jelly feels too thick for painting.
4. Paint a thick sheet of paper using a brush or a roller and allow to dry.

♥ **TIP** If you want to keep the paintings flat, place a thin paper and a weight on them when they are half dry.

24 COLOURING PLA WITH CHLOROPHYLL

Tito F. Williams II, CHEMARTS *Summer School 2018*

Pigments can be extracted from plants and used in various applications. Some natural pigments fade and change over time as a result of oxidation by air. This recipe demonstrates how chlorophyll from plant leaves can be applied to polylactic acid (PLA). The plastic forms an air barrier around the pigments, making the colour last longer.

INGREDIENTS

20–50 g Fresh plant leaves
25 g Polylactic acid (PLA)
250 ml Ethanol

EQUIPMENT

Soxhlet extraction apparatus
Batch mixer (Brabender)
Wide beaker
Fume hood
Knife and cutting board (or blender)

METHOD

➔ PIGMENT EXTRACTION

1. Gather fresh plant leaves of your choice.
2. Chop the leaves into small pieces by hand or using a blender.
3. Load the thimble of the Soxhlet apparatus with the chopped leaves and extract using ethanol until the drops are colourless.
4. Pour the extract solution into a wide beaker and let the ethanol evaporate in a fume hood.
5. Scrape the paste from the bottom into a sealable jar.

✱ **SAFETY** This recipe can only be conducted in a proper laboratory setting. If you are not familiar with the extraction process, please ask for guidance from laboratory personnel.

➔ BATCH MIXER FOR MELT MIXING THE POLYMERS

6. Heat the batch mixer above the melting point of PLA (in this case 175 °C).
7. Place the PLA into the mixer.
8. Add the pigment to the mixer.
9. Mix for no more than 30 seconds.
10. Remove the coloured bioplastic from the mixer and store.

♥ **TIP** Do a test series of different amounts of pigment to vary colour density. You can also test other pigments from nature.

♥ **TIP** To take your polymer tests further, you can mill the bio-plastic pieces into small granules. With granules you can continue to test using a 3D filament extruder or mini injection moulding machine.

LONG FIBRES FROM NATURE

Lignin and/or pectin glue plant cells together depending on the plant tissue. Lignified bast fibres are present in, for example, the inner bark of willow or linden and in the stems of nettle, hemp or flax (linen). Cooking the willow bark or nettle stem in baking soda, i.e. sodium bicarbonate, degrades pectin but not lignin, and retains long bast fibres, while the surrounding tissue softens and separates from them. However, the retting of textile fibres such as flax and hemp, is done by merely soaking them in water in certain conditions. The inner bark of linden can also be separated by retting. Bast fibres have several usages in textile production and as reinforcement in composites.

CONTENTS

25 Bast fibres from willow bark **122**

25 BAST FIBRES FROM WILLOW BARK

Tapani Vuorinen & Jinze Dou, CHEMARTS 2017

Willow is the common name for trees and shrubs of the Salix genus. Fast-growing willow hybrids have been developed for bioenergy crops. This recipe processes natural materials from willow inner bark for craft experiments. Willow bark peels easily, especially in late spring when the active growth season has started. Different willow species and hybrids may have different fibre properties and produce different colours, varying from pink to almost black.

INGREDIENTS

Willow stem or branch
Baking soda (sodium bicarbonate)
Water

EQUIPMENT

Knife
Large pan and stove

METHOD

1. Cut the stem or branch to the desired length.
2. Remove the dark outer bark by scraping it off with a knife. Leave the inner bark intact.
3. Make a longitudinal cut on the inner bark along its whole length using a knife, and pull it apart. If the bark does not separate, heat the stems in hot water for 15–30 min (80–100 °C).
4. Weigh the separated inner bark.
5. Place the bark into a large pan and add enough water to cover it. Add baking soda, at least one tenth of the weight of the bark.
6. Heat to boiling and cook for an hour. Beware; the mixture boils over easily.
7. Add cold water to cool, and wash the bark. For soft and flexible fibres, rub and separate the material into thin bast fibres by hand in the water. Keep the material moist or wet until you have completed the fibre separation. Separating the fibres by hand requires time and patience.
8. Dry the fibres on newspaper or other water-absorbing material. Avoid staining your clothes with the wet fibres

♥ **TIP** While cooking, various small-sized molecules such as sugars and aromatic substances dissolve, forming an intensive, typically reddish colour. This natural dye from willow can be used to colour textiles or other materials into red brown tones.

PAPERMAKING

Paper is the most well-known material produced from wood. However, paper was originally made from plant-based long fibres and for example, old linen fabrics were used as a raw material. In many countries, paper waste is collected and efficiently recycled into new products.

CONTENTS

26 Making paper sheets **126**

26 MAKING PAPER SHEETS

CHEMARTS *team 2016*

In a well-equipped workshop or laboratory, a hand sheet former machine can be used to make paper sheets, but paper and cardboard-like materials can also be prototyped simply using a mould and deckle. These tools are also easy to take on an excursion or a field activity. No chemicals are needed, just pulp or paper and water.

INGREDIENTS

Wood pulp sheets, waste paper or cardboard (as soft and untreated as possible)
Some natural materials such as leaves, plant parts or flowers
Water

EQUIPMENT

Bowl or bucket
Hand blender
Container
Mould and deckle
Absorbent paper or a fine towel

You will need two identically-sized frames, one with a screen/mesh (called a mould) and one without (called a deckle). You can buy a papermaking set from a hobby store, or make one yourself.

METHOD

1. Shred the pulp sheets or paper/cardboard into small pieces, add water and let the mixture stand overnight.
2. Use a hand blender to mix the soaked material until the fibre suspension is even.
3. Fill a large container with water and add the soaked pulp (and some other materials if you want). Mix well.
4. Take both the frames, put the mould underneath (screen/mesh upside) and the deckle on top, hold them together with your hands, slide them at a 45 degree angle into the bottom of the container, straighten the frame underwater and lift it carefully to evenly scoop up the fibres.
5. After taking the frame from the water you can add some materials like dried flowers to the surface. Let the water drain away and remove the deckle.
6. Turn the mould upside down to flip the paper sheet onto a drying surface (absorbent paper or a fine towel)
7. Raise the mould carefully, starting from one edge.
8. Let the paper sheet dry on a surface for a while. When drying on absorbent paper, move the sheet once to make sure it doesn't stick to the surface.
9. If you want to prevent curling, place the half-dry sheet between absorbent papers and under a weight, or use a hot press.

♥ **TIP** If your experiments fail, you can always put the material back into the water, stir well and make a new paper sheet.

GROWING MATERIALS

The idea of growing materials has become very popular in recent years. Although the focus of this book is on wood and plant-based materials, we decided to share the basic recipe for kombucha leather, tested by CHEMARTS students. If you are interested in this topic, plenty of information and DIY recipes for fungal materials such as mycelium, and for materials produced by microbes such as kombucha, can be found on the internet. Some companies are already developing and scaling up technologies for this kind of innovative material production.

CONTENTS

27 Growing kombucha **130**

Bacterial cellulose sample by Ingvill Fossheim, 2018. Her research culminated in the utilisation of bacterial cellulose in costume design in a dance performance called Posthuman Days, produced by Zodiak, Centre for New Dance, Helsinki.

27 GROWING KOMBUCHA

CHEMARTS *team 2016*

Cellulose is produced not only by plants, but also by some microbes. Bacterial cellulose (BC) can be obtained through, for example, Kombucha tea fermentation, during which bacteria, together with yeast, form a cellulose pellicle at the top of the medium. This culture takes its shape from its container, making it possible to create custom shapes. When a thick cultivation dries, the bacterial cellulose sheets are durable and have a leather-like feel. Thin mats might dry brittle. The material is not water resistant.

INGREDIENTS

2 l Water
2 bags Green tea
200 ml Cider vinegar
200 g Sugar
Scoby (Piece of living kombucha)

EQUIPMENT

Scales
Stove and pan
Container (plastic or glass)
Thin fabric (bigger than container)
(Baking paper)
(Oven)

METHOD

➜ TO PRODUCE THE GROWING MEDIUM

1. Heat up the water to boiling temperature of 100°C.
2. Turn off the heat and add the green tea bags, let them soak for 15 minutes.
3. Remove the tea bags and add the sugar. Mix until the sugar dissolves.
4. Cool down the mixture to 30°C or below.
5. Mix in the cider vinegar.

➜ FOR THE GROWING

6. Wash the growing container well before use.
7. Pour the growing medium into the container and make sure that the liquid is at least 2–3 cm deep. Add the scoby.
8. Secure a piece of fabric on top of the container to keep out fruit flies.
9. Grow in a ventilated place at a warm temperature (ca. 25 °C) for 2–4 weeks. The cellulose mat starts growing on the surface in a few days. The growing station may produce an odour.
10. When the cellulose mat is 2 cm or thicker, you can remove it from the container.
11. Wash the mat with mild soap and water. Avoid scrubbing the surface to keep the texture intact.
12. Dry on a non-stick surface (for example baking paper) in an oven at 30–40°C until dry or at room temperature for several days or weeks.

→ *Inka Mattila tested in 2018 how self-made growing mediums from nature can be used to produce bacterial cellulose.*

✱ **NOTE** Always use rubber gloves when handling the container, scoby and the medium to avoid contamination. Do not use metal containers as their antimicrobial properties might prevent growth.

♥ **TIP** Add more growing medium to the container if you wish to prolong the growth. Try to add the new medium without sinking the growth from the surface.

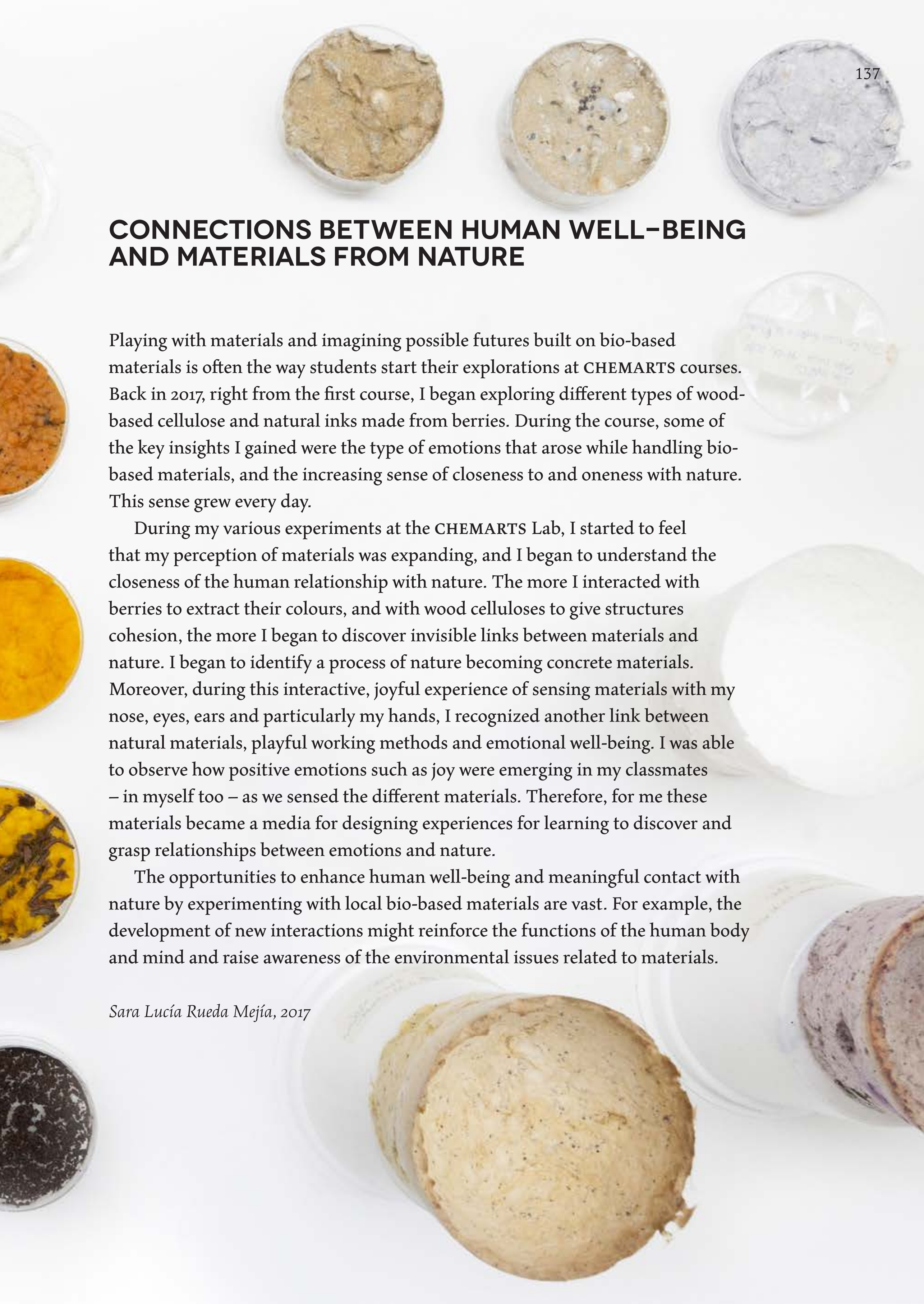
♥ **TIP** In a laboratory you can easily sterilize the container using a spray bottle of 70% ethanol, and terminate the growth in ethanol.

4 INSPIRATION

WORKING WITH NATURAL MATERIALS: EXPERIENCES OF CHEMARTS STUDENTS

Since the summer of 2012, hundreds of students have been working with bio-based materials in the Aalto University CHEMARTS laboratory. Interdisciplinary hands-on learning experience often have a great impact on the students' thinking. Many students have started the introductory CHEMARTS courses and then continued with three-month CHEMARTS Summer School, a bachelor's thesis, a master's thesis and, in some cases, even doctoral studies. Here, several students tell us about their experiences of working with natural or bio-based materials.

Musical instruments made of plants such as rhubarb, birch, cones. During the CHEMARTS *Summer School 2019 Katri Oikarinen wondered if plants could act as a source of music, and finally composed and recorded a song together with them.*



CONNECTIONS BETWEEN HUMAN WELL-BEING AND MATERIALS FROM NATURE

Playing with materials and imagining possible futures built on bio-based materials is often the way students start their explorations at CHEMARTS courses. Back in 2017, right from the first course, I began exploring different types of wood-based cellulose and natural inks made from berries. During the course, some of the key insights I gained were the type of emotions that arose while handling bio-based materials, and the increasing sense of closeness to and oneness with nature. This sense grew every day.

During my various experiments at the CHEMARTS Lab, I started to feel that my perception of materials was expanding, and I began to understand the closeness of the human relationship with nature. The more I interacted with berries to extract their colours, and with wood celluloses to give structures cohesion, the more I began to discover invisible links between materials and nature. I began to identify a process of nature becoming concrete materials. Moreover, during this interactive, joyful experience of sensing materials with my nose, eyes, ears and particularly my hands, I recognized another link between natural materials, playful working methods and emotional well-being. I was able to observe how positive emotions such as joy were emerging in my classmates – in myself too – as we sensed the different materials. Therefore, for me these materials became a media for designing experiences for learning to discover and grasp relationships between emotions and nature.

The opportunities to enhance human well-being and meaningful contact with nature by experimenting with local bio-based materials are vast. For example, the development of new interactions might reinforce the functions of the human body and mind and raise awareness of the environmental issues related to materials.

Sara Lucía Rueda Mejía, 2017

HOPE NEEDED: TACKLING CLIMATE ANXIETY THROUGH MATERIAL EXPERIMENTATION

Developing sustainable materials substantially benefits our environment. But how does it contribute to socially related improvement? During our journey of material experimentation in the CHEMARTS Summer School 2019, we delved into the interconnecting relationships between biomaterials, climate change and humans. We attempted to explore the possibilities to have an impact on not only environmental but also social sustainability.

People often lose sight of the fact that climate change is closely related to human emotions. The menace of climate change may harm individual mental health, making people *"feel scared, sad, depressed, numb, helpless and hopeless, frustrated or angry"* (Fritze et al. 2008), and even deny the severity of climate-related issues. Climate change is located in the intersection between environmental and social problems.

At the beginning of our project, we sought to create materials associated with certain emotions triggered by climate issues. We decided to focus on using agricultural waste: tomato stems from green house cultivation. However, we soon realized that the emotions linked to the materials varied from one individual to another. Rather than defining the feelings evoked by the materials, we probed into the diverse attributes of biomaterials, enabling them to convey the complexity of our climate-related feelings, and providing the audience with an opportunity to perceive and confront these issues. In addition, the material experimentation represented our small but meaningful action as part of climate activism. In line with the United Nations Sustainable Development Goal (SDG) #13 Climate Action, we utilized these plant residues, which to a certain degree served to fight against the overuse of resources, aiming to arouse positive emotions in people and mobilize them to make behavioural changes in terms of climate issues.

When dealing with climate change, emotions and feelings are unavoidably aroused, of which we are sometimes unaware of these. Our intention was, through material action, to create awareness of these emotions, engage with the issues, create positive emotions, and take further action to fight against eco-anxiety and climate change, as well as advance social sustainability in accordance with SDG #3 Good Health and Well-being and environmental sustainability.

Yu Chen & Chiao-wen Hsu, 2019

Fritze, J. G., Blashki, G. A., Burke, S. & Wiseman, J., (2008). Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing. International Journal of Mental Health Systems, 2(1), p. 13–18. Available from: doi:10.1186/1752-4458-2-13

HOW TO USE TREES IN A SUSTAINABLE WAY: THE ALDER PROJECT

It's time to revise the way we utilize forests and trees as mere materials. Forests are of great value to both the environment and human society. Trees play an important role in stabilizing conditions on our planet, but they also have a value of their own. It is increasingly important to understand trees, forests and their complicated processes. We need to weigh our choices and justify the use of wood and our methods of harvesting in relation to other values. For example, the monoculture of planted forests is a threat to biodiversity and forest well-being, and limits future possibilities in terms of materials. By understanding forests' natural processes we can hopefully find a balance and create a more sustained forest industry.

The Alder Project seeks to obtain a deep understanding of forests and wood as materials to be used for design purposes. It explores ways in which to use the whole tree more soundly and respectfully, understanding its origin. Currently, more than half of the material of every tree trunk cut may become inefficiently used byproducts: for example, branches, sawdust, and bark. The Alder project researches the undiscovered potential of and possibilities for these materials.

As a part of this project, I chose a Grey Alder tree in my family's garden and cut it down. I sawed and studied the tree as material, while seeking ways to avoid material loss and add value to its applications. From the tree boards I am making long-lasting pieces of furniture, and the leftovers are being used in research and as material for fibre-based bowls. The Grey Alder is a common tree in Finland. It is rarely used, never deliberately planted and has a bad reputation as a trash tree, but it is nevertheless an important species for forest biodiversity and soil nutrition.

Saara Kantele, 2019

WOODEN CERAMICS

Wooden Ceramics is an experimental design project that explores how traditional ceramic techniques can be applied in a new material field to create 3D shapes. It began as a personal project with a series of material behaviour tests with nanofibrillar cellulose (NFC). The approach was to use a two-piece plaster mould. The inner part of the mould controlled shrinkage while the plaster helped remove the water from the NFC. The resulting bowl is made of 100% NFC. It is light, hard and even water-repellent, but softens if placed into water for a few days.

Nina Riutta, CHEMARTS 2017

PRINTING 3D STRUCTURES WITH CELLULOSE

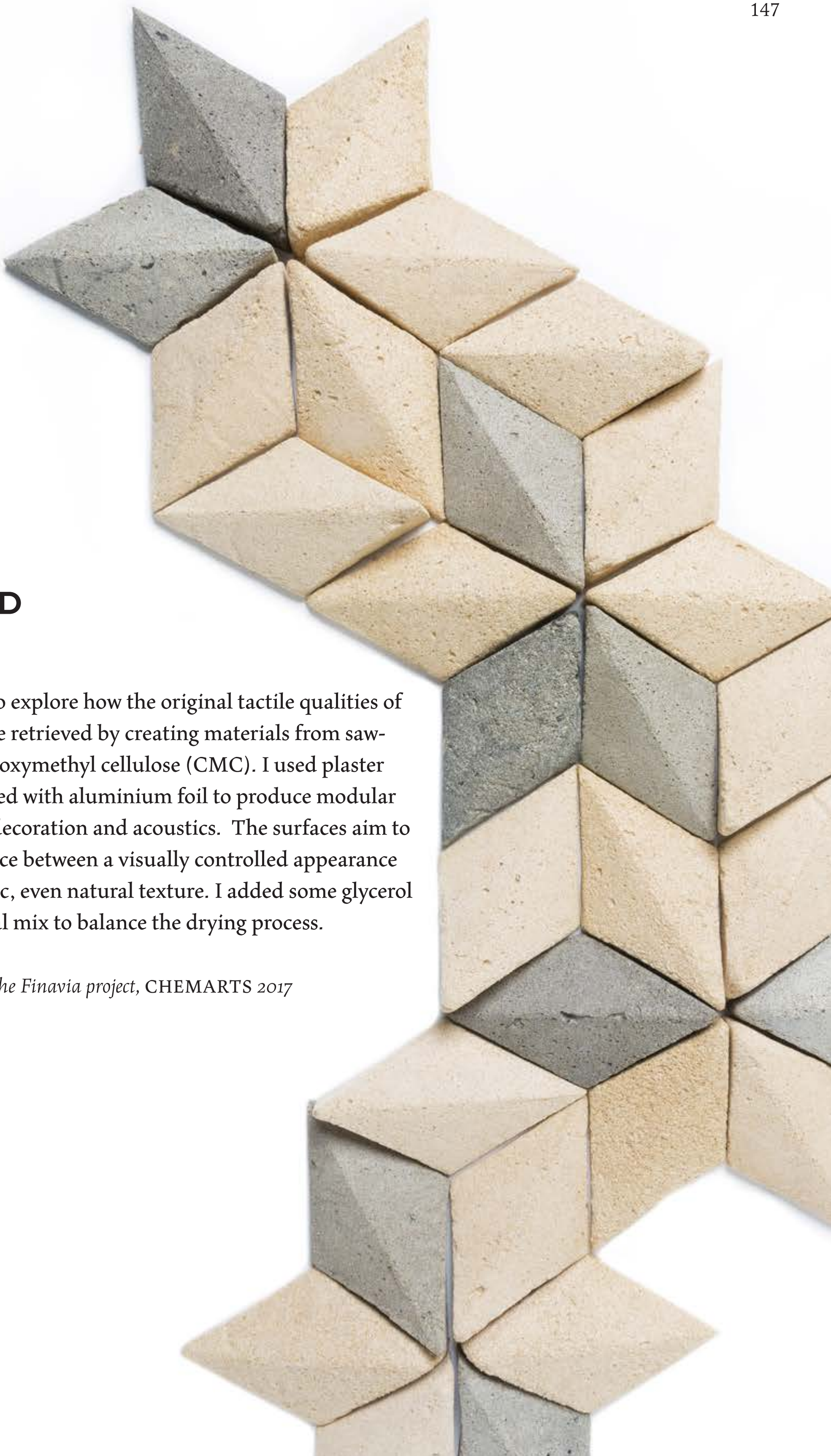
3D printing of cone-like structures on top of a mould was performed using air pressure extrusion and manual syringe extrusion. Nanofibrillar cellulose (NFC), microfibrillar cellulose (MFC) and water were combined in different proportions to observe the paste's printability and the properties of the dried artefacts.

Anastasia Ivanova, CHEMARTS *2017*

NANOCELLULOSE AND SELF-ASSEMBLY IN DESIGN

Self-assembly is a process in which components form an organized structure or pattern as a consequence of specific, local interactions among the components themselves. This project explored whether the shrinking and curling caused by water evaporation from a nanocellulose substance could potentially be applicable in this self-assembly context. It essentially asked: can a two-dimensional design be created, which through the process of drying would shrink and curl itself into a pre-decided, specific 3D shape. The materials used for the mixtures were nanocellulose and sawdust. These samples exemplify different degrees of curl based on the application thickness, the contents and ratios of the mixture itself, the structure of the directing material (paper-thin plywood sheet, aluminium foil), and the heat distribution during the water evaporation process.

Lumi Barron, CHEMARTS *Summer School 2017*



REWOOD

My aim was to explore how the original tactile qualities of wood could be retrieved by creating materials from sawdust and carboxymethyl cellulose (CMC). I used plaster moulds covered with aluminium foil to produce modular wall tiles for decoration and acoustics. The surfaces aim to create a balance between a visually controlled appearance and an organic, even natural texture. I added some glycerol to the material mix to balance the drying process.

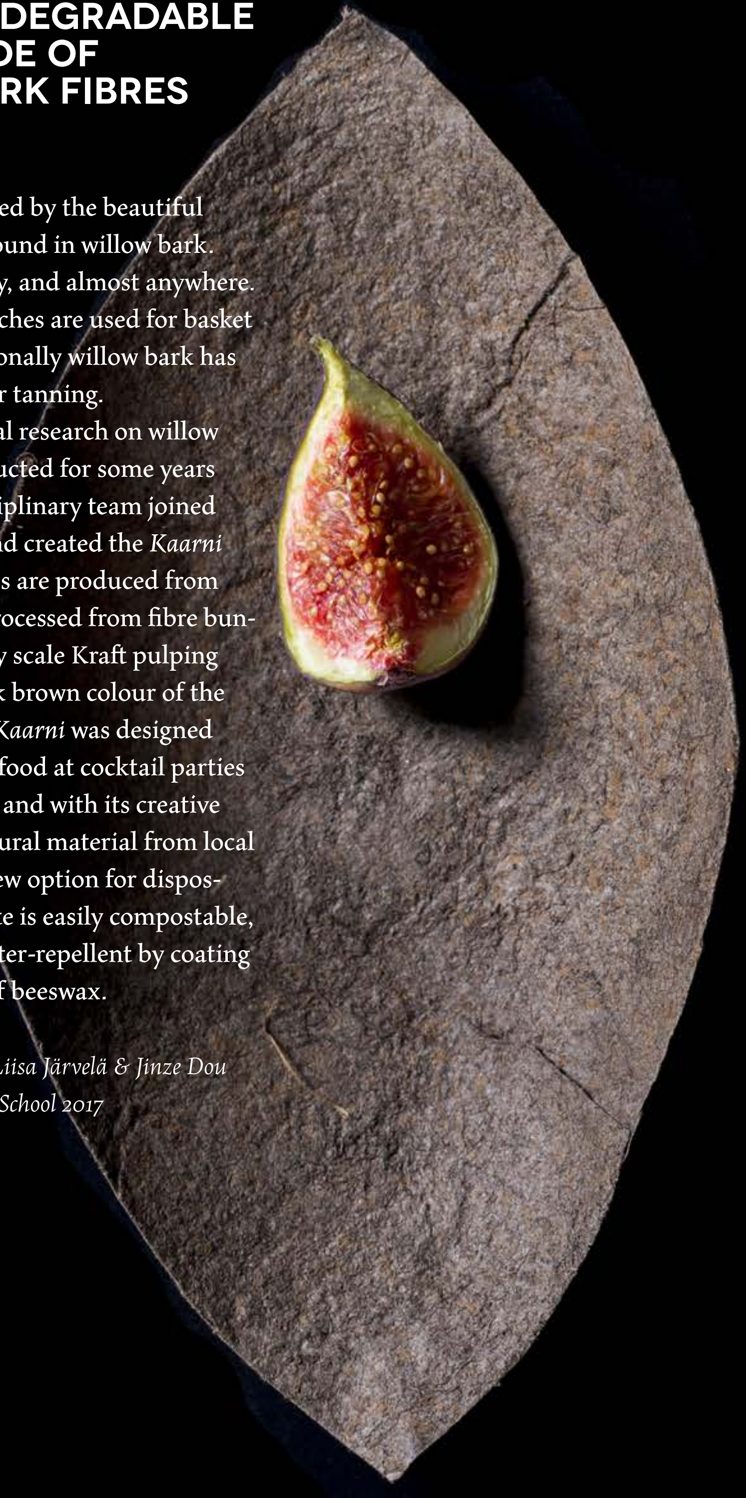
Linda Vanni, The Finavia project, CHEMARTS *2017*

EARTH TO EARTH – EXPERIMENTS WITH A BIODEGRADABLE URN

Earth is an abundant material; it can be found everywhere.
It is also one of the planet's most ancient construction materials. Microfibrillar cellulose (MFC), a wood-based substance, can be used to bind it together. These samples seek to explore the potential of this compostable composite material in product design. The material is water-sensitive and easily biodegradable. The best ratio was three parts earth, five parts MFC.

Lotfi El Salah, CHEMARTS *Summer School 2017*

KAARNI BIODEGRADABLE PLATES MADE OF WILLOW BARK FIBRES



Our team was inspired by the beautiful long fibre bundles found in willow bark. Willow grows rapidly, and almost anywhere. Flexible willow branches are used for basket weaving, and traditionally willow bark has been used for leather tanning.

Scientific material research on willow bark had been conducted for some years before our transdisciplinary team joined forces with others and created the *Kaarni* project. *Kaarni* plates are produced from willow bark fibres processed from fibre bundles using laboratory scale Kraft pulping machinery. The dark brown colour of the material is natural. *Kaarni* was designed especially for finger food at cocktail parties or outdoor festivals, and with its creative design and 100% natural material from local sources, it offers a new option for disposable dishes. The plate is easily compostable, and can be made water-repellent by coating it with a thin layer of beeswax.

Eveliina Juuri, Sanna-Liisa Järvelä & Jinze Dou
CHEMARTS *Summer School 2017*

WOOLLULOSE

Driven by a deep feeling of nostalgia, with the Woollulose project, I wanted to pay homage to my memory of a shepherd's hut surrounded by humble sheep. By blending southern wool and northern wood-based cellulose, I discovered new textures and shapes with intriguing haptic properties. The processes of heating and pressing combined with a calcium chloride bath gave birth to shapes and textures, resulting in experimental material studies conceived through nostalgia. The ingredients were MFC, NFC, glycerol, CMC, lamb's wool and natural pigments such as turmeric and pine cone.

Surabhi Nadig Surendra, CHEMARTS *Summer School 2018*

TO–MATTER
PAPER SHEETS FROM TOMATO STEMS

The idea of my project was to explore how the sidestreams of tomato production could be used for sustainable packaging materials. Tomato stems and leaves make up roughly 20% of the total fresh material of an average yield. As the dry matter content of stems and leaves is higher than that of tomatoes, they account for approximately 30–40% of the total dry matter content of the whole plant. Currently, this green biomass (stems and leaves) is mostly treated as waste. A tomato stem contains cellulosic fibres and can be used in cardboard/paper manufacturing. Farmers could gain value from the biomass by local packaging production, thus also reducing their carbon footprint.

In some experiments, I used only the inner or outer layers of the stems, and mixed the material with pine, birch pulp or recycled pulp and microfibrillar cellulose (MFC). I also tried adding long fibres such as hemp for durability. To process the fresh and dried tomato stems, I used various methods such as cooking, grinding or foaming.

Meri-Tuuli Porras, CHEMARTS *2019*

NOT A MATTER OF TASTE
A MATERIAL EXAMINATION OF AN EDIBLE CELLULOSE COMPOSITE

The initial idea for our project was born when we met Esko Paatelainen, who produced *pettu*flour using traditional methods. *Pettu*flour is a product made from pine bark and was used in Finland as a substitute in baking, for example, during World War II. To refresh the image of *pettu*, we came up with the idea of using it to produce edible dishes. In order to bind the dry, fine flour, we needed something to mix with it. We learned that bacterial-grown cellulose made from coconut water, Coco de Nata, is a delicacy in Asia. This cellulosic treat is non-toxic and good for digestion. Could it be grown out of pine juice and then combined with *pettu*? After several experiments with these ingredients, our project resulted in light, edible bowls.

Maija Järviniemi & Outi Mustonen
CHEMARTS *Summer School 2015*

HAVU – COSMETICS FROM FINNISH NATURE

Solid wood can be used for high added-value products in an innovative way. From my first day at the CHEMARTS Summer School, I wanted to combine branding and design with bio-based materials, and at the same time learn the basics of cosmetic chemistry. My inspiration comes from Finnish nature, wood and minimalism. The ingredients of Havu cosmetics are completely natural and the products could be certified as natural cosmetic products.

Lumi Maunuvaara, CHEMARTS *Summer School 2017, Co-founder of Havu Cosmetics*

AURORA – NATURAL SUNSCREEN FROM SPRUCE BARK EXTRACT

Our team wanted to create a natural alternative for skin UV protection by using spruce bark which is known to have antibacterial and UV protective properties. We tested several recipes to achieve a pleasant texture and consistency for the cream. We processed the spruce bark extract in a laboratory setting and added it to the mixture. We tested the UV absorption of the cream using sun-sensitive paper, which is also used in cyanotype photo-making, and the test showed that the cream provided a UV protection factor similar to that of commercial products.

Aurora sunscreen contains only natural ingredients and can be either fragrance-free or fragranced by spruce essential oil, extracted from oleoresin. The ingredients of the cream are natural organic oils (coconut oil, jojoba oil), camellia oil, olive squalane, aloe vera extract, plant-based e-wax (emulsifier), green tea extract, water, and spruce bark extract.

Anna Kokki and Mengmeng Sui, CHEMARTS *Summer School 2017*

PADIWALA – EXPERIMENTS WITH RICE STRAW WASTE

Rice straw is a major agricultural by-product in Asia. As we shared this continental background, we delved into the application of rice straw waste as a sustainable source for future materials. We experimented with rice straws in as many ways as possible, mixing it with, for example, NFC, glycerol and $CaCO_3$. The cultural fusion gave rise to Padiwala, a contemporary material to study in the future.

Talisa Dwiyani & Miki Todo, CHEMARTS *Summer School 2018*

BIO SHADE – MATERIALS FOR LAMP SHADES

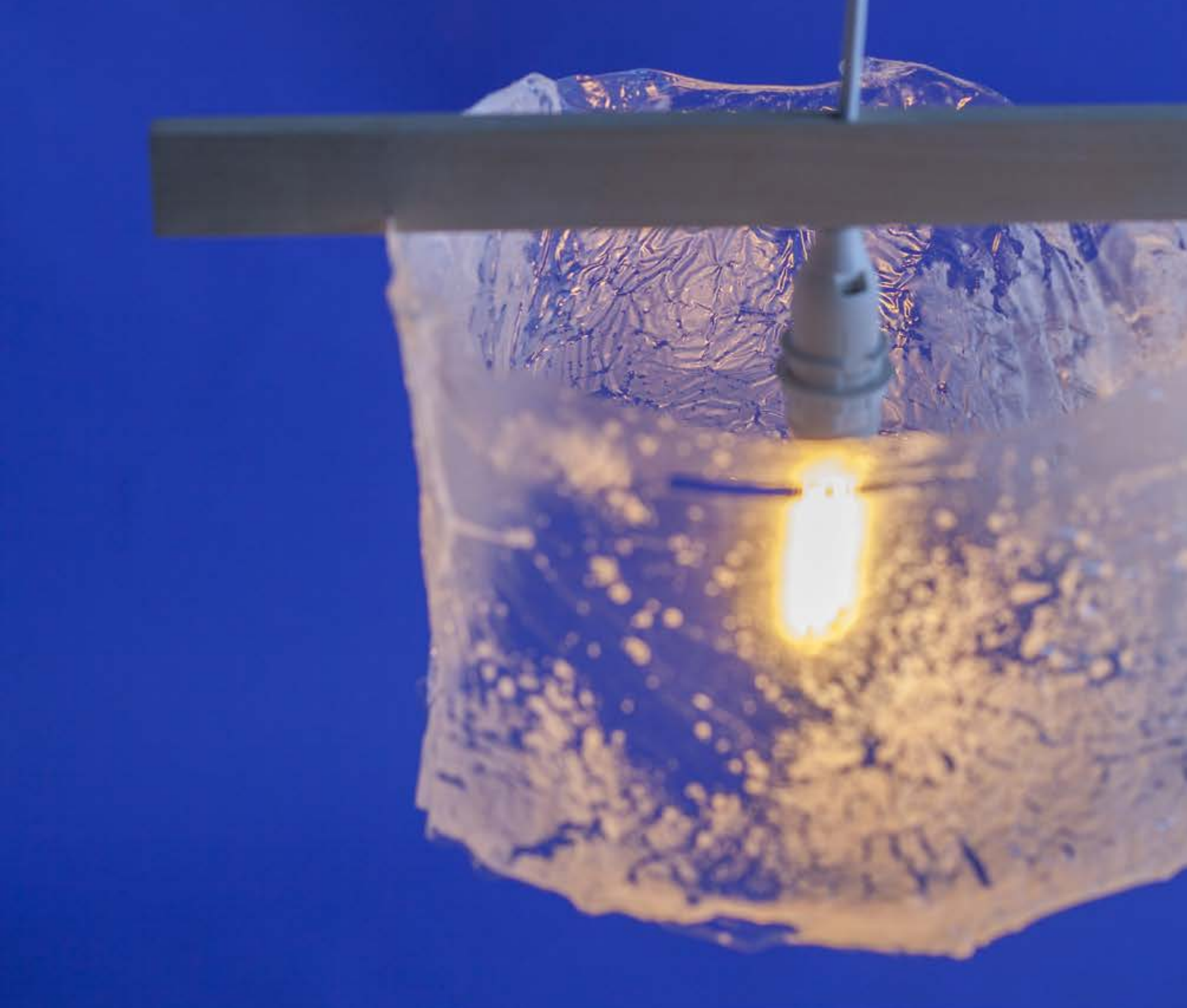
I was inspired by Finnish nature and tried to capture its beauty using bio-based materials. Bio Shade is a series of experimental materials for lampshades, and creates the feeling of a forest with its shadows. The samples are made from paper yarn and different combinations of pulp, nanocellulose (NFC) and carboxymethyl cellulose (CMC). I dyed the materials using natural dyes made from nettles, willow and lignin, and coated two of them with birch bark.

Katja Utriainen, CHEMARTS *Summer School 2017*

CELLULOSE IN MOTION

Luminaire is made from wood-based materials. The shade comes from cellulose triacetate (CTA) and the frame is made from Finnish aspen. As a thin layer of organic matter, CTA is translucent and allows light to pass through beautifully. It can be bent and is water-resistant. The production of the shade is based on the centrifugal force of rotation. The aspen frame's design is minimalistic to draw attention to the shade. In this case, cellulose triacetate was dissolved in chloroform. This process can only be undertaken in laboratory conditions with proper safety equipment and professional guidance.

Nina Riutta, CHEMARTS *Summer School 2016*



GROW YOUR OWN LAMP!

My design process usually starts from a material. This time I decided to produce it myself instead of using a commercial material, and grew kombucha leather in my kitchen. I was fascinated by the concept of growing a sustainable material from just sweetened tea and starter culture. You can grow only as much as you need and you don't produce any waste: recycling is no problem either because bacterial cellulose is a biodegradable material. The static growth process is slow, and took eight weeks.

Monika Faidi, CHEMARTS *Summer School 2016*

TRANSIENT SURFACES FOR FASHION

Motivated by environmental and ethical issues in the fashion industry, Transient Surfaces was born from the need to replace fossil oil-based materials (ex. PU and PVC). My goal became to create a cruelty free, biodegradable, leather-like material. Explorations of NFC, growing bacterial cellulose and kombucha can develop the structure of NFC fibre films to make them suitable for clothing. Extensive experimentation and development resulted in a final product of a dress of clasped pieces of NFC films. Although incredibly unpredictable, the material created a level of spontaneity and life in the final piece.

Julia Strandman, CHEMARTS *Summer School 2018*

EXTRACTIVE NOVELTIES

My initial idea was to combine antibacterial pine extractives with textiles, aiming to inhibit body odour on garments. Pure sweat does not smell. The bacteria on our skin degrade sweat into components that have an unpleasant odour. So, my idea was to inhibit these skin bacteria with natural ingredients, pine extractives. I separated extractives from pine bark and needles using different solvents. After evaporating these solvents, I was left with pure extractives, which I dissolved in water and used in microbiological testing. I wanted to see if my hypothesis was correct: whether pine extractives actually inhibit the growth of skin bacteria. For the testing I used pure strains of *staphylococcus epidermidis, staphylococcus hominis* and *propionibacterium acnes* on agar plates. I also tested whether pine extractives combined in textile pieces could inhibit the growth of bacteria. The results were positive: the bacteria did not grow on the plates with extractives and even better, the textile pieces combined with extractives formed an inhibitory cycle around them on the plates, which means that the pine extractives also worked when combined with textiles. These extractives could be combined in a lotion to obtain better skin contact for body odour control, or used against other bacteria on textiles, for example in scrubs and bandages.

Laura Niemelä, CHEMARTS *Summer School 2015*

EXPERIMENTS WITH FUNGAL MATERIALS

This project was an exploration of mycelium using different types of fungi mixed with other natural agents such as bacterial cellulose, nanocellulose and wood. The result – new kinds of fungal materials and pigments with different properties – could serve as a sustainable alternative for creating accessories or household objects in the future.
The project was made possible by close collaboration with the Technical Research Centre of Finland (VTT).

Manuel Arias Barrantes
CHEMARTS *Summer School 2017*

ALL-CELLULOSE NON-WOVEN GARMENT

The idea of our project was to experiment with a fast, sustainable production process for throwaway garments, to serve the needs of the fast fashion industry, for example. If we can't change the unsustainable fast fashion system quickly enough, could we replace existing materials with biodegradable ones? As a result of material experiments, we created a 100% zero waste garment produced by foam-forming technology, using sodium dodecyl sulphate (SDS). We prepared a metallic mould in the shape of a garment, and cast the foamed pine pulp and viscose fibres into the mould. The fibres were dyed using reactive textile dyes, and when the garment was dry, we printed it with pigments mixed with nanocellulose paste. Cellulose buttons were made in collaboration with Iines Jakovlev. Our project was supported by the Technical Research Centre of Finland (VTT).

Fanni Lyytikäinen and Anna Semi, CHEMARTS *Summer School 2017*

RE-IN-COLOURED – RECYCLING COLOUR USING THE IONCELL PROCESS

Ioncell-fibre production is one of the research projects of the School of Chemical Engineering at Aalto University (*www.ioncell.fi*). The principle of the process is to use a special ionic liquid solvent to dissolve cellulose and then regenerate it to produce filaments by spinning. The solvent used in this process is known to be more environmentally friendly than those currently in use in similar textile production. Fascinated by the successful production of filaments from Finnish birch pulp and recycled paper and cardboard, we wanted to dive into the subject of waste material utilization. We explored waste materials such as a used cotton jacket and jeans, as well as so-far unexploited natural resources such as bark and needles. We also wanted to see whether the colour would survive the chemical recycling process. For our tests, we had access to the fibre spinning line at a laboratory.

We succeeded in producing several filaments in different colours, which demonstrates that dyed waste textiles can be re-spun. Colour preservation varies depending on the dyeing methods of the original fabric: for example the waste jeans gave the regenerated filaments a lighter colour than the dark blue jacket.

Eugenia Smirnova & Zhen Zeng, CHEMARTS *Summer School 2015*

WILD DYE

The incentive of the Wild Dye project was to make our fashion and textile design practices more sustainable by learning about natural dyes and screen printing. Our focus was on making dyes from so-called foreign species currently growing in Finnish nature and overtaking our natural flora. We mainly used Rosa rugosa, Lupine and Fireweed but also some other plants for the dyes; and wool, viscose/rayon and silk fabrics as materials. We created patterns on textiles with pH-altering printing pastes, which resulted in multi-coloured fabrics using only one natural source of colour. We also tested the use of cellulose-based printing pastes such as carboxymethyl cellulose (CMC). The pH level was altered using baking soda, lemon juice and vinegar.

Aleksandra Hellberg & Jenny Hytönen
CHEMARTS *Summer School 2019*

SHIMMERING WOOD: COLOURS THAT NEVER FADE

Nature's brightest colours – like those found in peacock feathers or butterfly wings – are created through microscopically small nanostructures. When light hits these structures, our eyes perceive their intense, vivid colours. Unlike traditional pigments or dyes, these colours arise only from the physical structure of the material, without the need for coloured chemical structures. Usually these structural colours are iridescent, turning typically muted and humble shades into shimmering colours. Shiny or glittery effects – very popular in fashion and design today – are usually created using toxic pigments, plastic-based materials, or metallic foils. This structural colour presents a sustainable alternative to these traditional colorants: it is produced from nontoxic cellulose nanocrystals in an economically viable process. Unlike most existing dyes, structural colour does not fade in sunlight.

Shimmering Wood is an interdisciplinary material research project in progress since 2016 at the School of Chemical Engineering at Aalto University.

The team consists of: Designer Noora Yau, PhD Student Konrad Klockars, Senior Researcher Blaise Tardy, and Professor Orlando Rojas.

INSIGHTS OF MATERIAL PROFESSIONALS: THREE VIEWS OF THE MATERIAL WORLD

Liisa Tervinen

To illustrate what it is like to work with materials in a commercial context, we interviewed material scientist Tekla Tammelin from the Technical Research Center of Finland (VTT); the Chief Creative Director and co-founder of OMUUS, Annina Verkkomäki; and the CEO and co-founder of Sulapac company, Suvi Haimi.

RESEARCHING CELLULOSE-BASED MATERIALS WITH TEKLA TAMMELIN

HOW DO YOU CREATE NEW MATERIALS? I think that this creation work is a combination of wide-ranging, strong knowledge regarding the building blocks of the new materials and their physical/chemical behaviour, curiosity, and openness to new ideas. This means openly interacting with people with multidisciplinary backgrounds, sharing your own ideas and believing that your fledgling ideas will be successful in the end. A positive attitude is a solid basis for success.

HOW DOES THE PROCESS START? This depends on the driver of the research. Sometimes the research idea is sourced from an existing challenge or a need related to the specific performance of the new material. Very often, inspiration comes from a specific feature of the bio-based building block or structure, which can be exploited in an unprecedented way in materials engineering. Sometimes the route to new areas starts from an unexpected finding in ongoing research.

WHAT IS THE ROLE OF (MULTIDISCIPLINARY) COLLABORATION? Collaboration brings multiple angles to the content of the research work. It also brings a social aspect, which broadens the mental dimension of the collaboration. One integral part is actively attending meetings and conferences outside your own area of expertise.

WHAT GUARANTEES SUCCESS IN A MATERIAL PROJECT? In addition to strong knowledge and a positive attitude, practical aspects also play a vital role. Success requires hard work and commitment to the research.

WHAT KIND OF FUTURE WOULD YOU LIKE FOR WOOD-BASED MATERIALS? The cellulose community has expanded and is attracting not only scientists from other research fields but also companies and industrial partners from various sectors. Polymeric cellulose and cellulose fibres have been part of our everyday lives in the form of textiles and paper products for hundreds of years. Over the last 15–20 years I would say that the progress in research (both fundamental and more applied research) related to the introduction of lignocellulosic materials in novel application fields has been taking huge leaps rather than steps. The basic understanding of the inherent features of cellulosic materials has dramatically increased. Research has been steered towards completely new application areas beyond the obvious areas such as textiles, papermaking and packaging (which are of course still relevant fields). Lignocellulosic components have been convincingly utilized in nanocomposites as optical materials, in electronic devices and sensor elements and as water purification materials, to give just a few examples. A huge materials portfolio indeed to be realized!

COLOR, MATERIAL AND FINISH DESIGN (CMF) WITH ANNINA VERKKOMÄKI

WHAT IS CMF DESIGN? Color, Material and Finish design (CMF) is an area of industrial design that focuses on the chromatic, tactile and marketable assets of product design. Although the focus on CMF design is mainly integral to the apparel and interior industries, this area is also growing in importance in the transportation and technology industries. CMF is used for product competitiveness, and to build emotional appeal and recognizability for a brand. CMF design is not merely something to be added after the design process, and it is more than differentiating products; it means learning to design on the level of all the senses. The most influential consumer groups such as Generation Z and the Millennials are placing more importance on stimulating the senses due the growing influence of digitalization, in which the physical relations are often blurred.

WHAT KINDS OF DEMANDS AND REQUIREMENTS DOES TODAY'S INDUSTRY POSE FOR THE MATERIALS USED IN PRODUCTS? When buying a product, consumers, especially the younger generations, are willing to buy from companies that contribute to a better tomorrow. Companies are noticing the potential that materials have to increase their products' competitiveness – not only through better market value, but also through sustainability, unique outlooks and innovative user experiences. Today, the sensory, aesthetic and technical properties of materials strongly impact their success.

WHAT ARE THE BIGGEST CHALLENGES FOR CMF PROJECTS? For each project, we need to find the right development partners – partners who share the skillset, ambition, vision and discipline to work towards a shared goal. In the optimal case, CMF and industrial design are already integrated into the concept phase, and designers work as a team with multidisciplinary specialists from various fields such as audio, mechanics, connectivity, marketing, user experience and interface design, as well as with suppliers to deliver holistic, material-driven and sustainable solutions.

WHAT ARE THE BIGGEST CHALLENGES WHEN WORKING WITH (NEW) MATERIALS? First, we need to determine which materials are actually available and applicable for a specific end product. Introducing new materials may not always be the right solution, as the validation and scaling of new materials into mass production takes time and requires a great deal of resources. In most cases, CMF works with existing materials: of which there are so many interesting ones that can be worked on and reformed into innovative solutions. New is not always the way forward.

WHEN SCALING UP FROM PROTOTYPES TO ACTUAL PRODUCTION, WHAT ARE THE KEY POINTS YOU HAVE LEARNED WHEN WORKING WITH DIFFERENT KINDS OF MATERIALS OVER THE YEARS? The level of productization in each project can vary, and should be specified at the beginning of each one. To give an example: a medical industry product requires medical grade materials, and if the designer ignores this requirement, or is just oblivious to it, the consequences for the client can be detrimental, as the product will not enter the market if it does not acquire CE (Conformité Européenne) or FDA (Federal Drug Association) certification. Design is always material driven. Each material and manufacturing technology has parameters that need to be understood and applied to the design language. If the design is not created in alignment with the technology requirements, this can lead to a lack of quality and the generation of waste from production, which in turn can cause low margins and unsustainable production.

WHAT KIND OF CHARACTERISTICS, SKILLS AND KNOWLEDGE DOES A CMF DESIGNER NEED? CMF designers use colours as tools: they have to know the properties of colours and understand which colours are possible for the given material, how a particular colour can be used for marketing in different product categories, and how colours affect consumer perception. CMF designers should also have very good knowledge of materials and production processes – also their limitations – and be able to design around these parameters. The communication between different stakeholders: business partners, marketing personnel, suppliers, industrial designers, engineers and supplier networks requires good communication skills. The ability to talk business is important for convincing and influencing the business audience. Communication is also important in terms of collaboration – cross-disciplinary teamwork skills are a valuable asset for CMF designers. As CMF is constantly evolving, a designer needs to be enthusiastic about continuous learning, self-motivated to search for information, curious about trends and consumer behaviour, and eager to develop the CMF field and its tools. One of the most important things for a CMF designer is to be creative and be able to think outside the box.

In most cases, CMF works with existing materials: of which are so many interesting ones that can be worked on and reformed into innovative solutions.

SULAPAC WOOD-BASED PACKAGING MATERIALS WITH SUVI HAIMI

WHY CREATE NEW WOOD-BASED MATERIALS? As a natural material, wood is safe for both people and the environment. It is a renewable resource, which makes it a climate-friendly alternative to traditional plastic, for example. It can often be locally sourced, which means savings in CO_2 emissions through logistics, leading to a smaller carbon footprint for the final product. The wood component also gives our Sulapac material a unique and beautiful appearance. It is important to note that we use wood waste, which is a side stream from industry.

HOW DOES ONE CREATE NEW MATERIALS? For Sulapac, safe and circular is the guiding principle throughout the entire innovation process. This means that every step of the value chain has been carefully considered from a sustainability perspective. Customer requirements is another core aspect on which our recipe development is based. No matter how sustainable a material is, if it fails to serve customer needs, it is worthless. Even though it is immensely important, being a sustainable choice is not enough – you have to be the best at what you do. Finally, standards and certifications are crucial, as they help ensure high quality and add credibility.

> *No player can succeed alone in achieving a more sustainable future: we have to take an interdisciplinary approach and work together across industries and sectors.*

HOW CAN A BUSINESS BE BUILT ON NEW MATERIALS? Fossil-based raw materials are no longer a desirable option, as they speed up climate change. Traditional plastic has also proven detrimental to our planet due to its littering effect and release of microplastics. Although enhancing mechanical plastic recycling is crucial, alone it is not enough to solve the global plastic crisis. New, sustainable innovations are needed: consumers have also understood this and are pressuring brands for more eco-friendly alternatives. With its sustainable wood-based innovation, Sulapac addresses all these challenges, while making sustainability a commercially viable choice.

WHAT ROLE DOES COLLABORATION PLAY? Cooperation with customers is key in our business. It is important to us that all our partners share our commitment to sustainability. Throughout the value chain, we work closely with brands and plastic product manufacturers who can process our material using their existing machinery and bring sustainable solutions to the market. An example of a jointly developed product is the ocean-safe straw we launched together with our partner Stora Enso. We also value collaboration in a wider sense and participate in working groups and networks such as the Ellen McArthur Foundation, with the aim of furthering the agenda of the circular economy and accelerating the introduction of new sustainable solutions. No player can succeed alone in achieving a more sustainable future: we have to take an interdisciplinary approach and work together across industries and sectors.

WHAT HAVE YOU LEARNED WHEN SCALING UP A MATERIAL PROJECT? Our material is safe and circular throughout the value chain and compromising this has never been an option. This means you have to keep sustainability at the core of all decision-making and clearly communicate your priorities to all your stakeholders. When scaling up, you also learn the value of a team with versatile experience and professionalism outside material expertise, which nevertheless remains at the heart of the business.

WHAT KIND OF FUTURE WOULD YOU LIKE FOR WOOD-BASED MATERIALS? Wood-based materials generally have huge potential as sustainable solutions, and I hope to see many new material innovations and applications emerging in the near future. I also hope that the regulatory environment will catch up with this change to ensure that truly sustainable solutions are identified and widely adopted.

SUGGESTED READING

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GLOSSARY

AALTOCELL™: Microcrystalline cellulose prepared using a dilute acid hydrolysis method developed by Professor Olli Dahl at Aalto University.
ABSORBENT PAPER: Paper grade developed for absorption of liquids.
ACETONE: An industrial, volatile organic solvent that can dissolve both polar and non-polar organic substances.
ALDEHYDES: Class of organic compounds that undergo specific chemical reactions. For example, aldehydes condense with phenols, forming polymeric compounds such as phenol-formaldehyde resin.
BACTERIAL CELLULOSE: Mat of thin cellulose fibrils produced by certain bacteria outside their cells. Bacterial cellulose can be grown in a specific space using silicone or other hydrophobic moulds.
BIO-BASED PLASTIC: Thermoplastic polymer made of ingredients that originate from nature.
BIOPOLYMER: Polymer produced by natural organisms, e.g. plants or bacteria
BIODEGRADATION: Material degradation that takes place in a biological environment, e.g. in soil or water.
CELLULOSE: The most abundant polymer in the world. One of the three main chemical components of plants, the two others being hemicellulose and lignin.
CHEMARTS: Long-term collaboration since 2011 between two Aalto University schools, The School of Chemical Engineering (CHEM) and The School of Arts, Design and Architecture (ARTS). CHEMARTS focuses on biomaterials, especially wood-based cellulose. It consists of interdisciplinary study courses and workshops, events and exhibitions. chemarts.aalto.fi
CHEMARTSING: A verb created by Tino Koponen to describe the special way of working on CHEMARTS courses.
CHEMICAL RECYCLING OF TEXTILE FIBRES: Recycling as polymers by disintegrating textile fibres to polymer (or monomer) level and rebuilding new fibres.
CIRCULAR ECONOMY: An industrial economy, the aim of which is to reduce waste and pollution by designing material flows in a circular manner. An alternative to the linear economy.
COMPOSITE: A material made of two or more components with different chemical or physical properties. The resulting composite material's characteristics differ from its original material components.
FILAMENT: Continuous textile fibre that is often cut into staple fibres for yarn production. Synthetic filaments and silk are also used in this way in textile production.
HYDROPHILIC: Characteristic of a substance or surface that prefers to attract or bind polar substances such as water. A drop of water spreads on a hydrophilic surface.

HYDROPHOBIC: Opposite to hydrophilic. Characteristic of a substance or surface that does not attract or bind polar substances such as water. A drop of water does not spread on a hydrophobic surface. A water droplet on a highly hydrophobic surface is perfectly round in shape.
IONCELL: New technology to produce cellulosic textile fibres out of pulp, paper, cardboard or cotton waste. It is based on research conducted at Aalto University and the University of Helsinki. ioncell.fi
MATERIAL SAFETY DATA SHEETS (MSDS): Collection of detailed information on the properties, safety risks and handling of individual chemical substances.
MYCELIUM: A mass of thread-like organization of cells – hyphae – of a fungus (or bacterial colony). In nature, hyphae grow in the soil or in the biological material that the fungus is degrading.
NON-WOVEN FABRIC: A planar structure of fibres or filaments bonded together mechanically, thermally or chemically.
PLASTER: A smooth paste made for example of gypsym and water which goes hard when it dries.
PHENOLS: Organic molecules in which one or more hydroxyl groups are directly bonded to an aromatic ring. Practically all plants contain phenolic substances in varying amounts. Lignin is a polymer of a few phenolic monomers. Large amounts of small phenolic molecules may exist in, for example, the bark and knot wood of trees.
PHENOL-FORMALDEHYDE RESIN: A mixture of synthetic phenol and formaldehyde that condenses to form a polymer, often used as a glue. The release of unreacted formaldehyde can be a health problem when phenol-formaldehyde resins are used in interior applications. Phenol and formaldehyde can be substituted at least partly by other phenols, such as lignin, and aldehydes.
PIGMENT, ORGANIC PIGMENT: A particle or substance that has a specific colour. White pigment particles such as calcium carbonate or kaolin are used as fillers or coating components in paper products, for example.
POLAR SUBSTANCE: A substance in which electrons are distributed unevenly between neighbouring molecules, creating electric charge differences between the atoms. Organic polar substances typically have a high oxygen content. Water and carbohydrates, such as sugars, cellulose and starch, are common examples of polar substances, whereas fats are non-polar. In practice, polar and hydrophilic are almost synonymous attributes of a material.
POLYMER: A molecule that consists of small, repeating building blocks called monomers. In the case of cellulose, the repeating building blocks are single units of glucose (sugar).
RECYCLABLE MATERIAL: A material that can be reprocessed through a system for further treatment or use.

RECYCLING: Unused or waste materials being reused or transformed into new materials and objects.
RENEWABLE RAW MATERIALS: Related to a natural resource, such as solar energy, water, or wood, which is never used up or can be replaced by new growth.
STILBENES: Organic molecules in which aromatic rings are bonded together with a conjugated double bond in between. Natural stilbenes may exist in wood and bark, for example, depending on the species. Pine heartwood and spruce inner bark are rich in hydrophilic, polyphenolic stilbenes that condense easily with aldehydes.
TEXTILE FIBRES: Natural or synthetic materials used for textile production. For example cotton, linen and wool are natural fibres. Several other natural materials such as wood cellulose can be used to produce manmade cellulose fibres such as viscose (rayon) or lyocell. The most common textile fibre today is polyester, a fossil-based synthetic fibre.
YEAST: Single-cell microorganism that belongs to the fungus kingdom. Yeasts are utilized in fermentation processes, for example, in the production of ethanol.
WOOD CELL: The basic unit of wood structure, a plant cell.

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Thank you all!

RESOURCES

Some ingredients and tools used in The CHEMARTS Cookbook experiments are not easily accessible, and some recipes require close collaboration with a company or research institute. *Nanofibrillar cellulose (NFC)* and *microfibrillar cellulose (MFC)* are mainly in pre-commercial production, but you can ask availability from local research institutions or companies focusing on bio-based materials.

Here we share a few ideas how and where you can find other supplies.

FOR INDIVIDUALS:

- For *pulp* experiments, you can use tissue papers from grocery stores or recycle paper such as newspaper or cardboard. Search for paper making kits and single cellulose pulp sheet providers from local craft stores or online.
- *Carboxymethyl cellulose* (CMC), *methyl cellulose* (MC) and *microcrystalline cellulose* (MCC) you can search from commercial e-sellers such as Amazon, Ebay or Alibaba.
- *Hydroxypropyl cellulose* (HPC) you may be able to find from commercial e-sellers, but it would be advisable to order it from a chemical company via some institution.
- *Baking soda, dishwashing liquid* and *food colors* you can buy from grocery stores.
- Nature is a great source for materials but take care of safety and make sure not to harm plants or other living things. See page 41.

FOR INSTITUTIONS:

- For large quantities of *pulp*, make an inquiry to a local pulp mill or wholesaler.
- *Carboxymethyl cellulose (CMC)*
  CAS Number: 9004-32-4, low viscosity 50–200 cP
  CAS Number: 9004-32-4, medium viscosity 400–800 cP
  CAS Number: 9004-32-4, high viscosity 1500–3000 cP
- Methyl cellulose (MC)*:* CAS Number 9004-67-5, viscosity 4,000 cP
- *Cellulose acetate (CA):* CAS Number 9004-35-7, acetyl content 40% in weight, corresponding to a degree of substitution (DS) of 2.5
- *Hydroxypropyl cellulose (HPC):* CAS Number 9004-64-2, average Mw ~80,000
- *Microcrystalline cellulose (MCC):* CAS Number 9004-34-6. In CHEMARTS, we use an MCC grade produced in Aalto University under the trade name AaltoCell™.
- *Sodium bicarbonate:* CAS Number 144-55-8

Aalto-C 1/2020

How can we make flexible and transparent wood-based materials? What kinds of materials can we derive from trees, while still respecting the preciousness of nature? Could the innovative use of renewable cellulosic materials change our material world?

The CHEMARTS Cookbook gives both simple and more advanced ideas and recipes for hands-on experiments with wood-based materials. The book showcases the most interesting explorations focusing on raw materials that are processed either chemically or mechanically from trees or other plants: cellulose fibres, micro- or nano-structured fibrils, cellulose derivatives, lignin, bark and wood extractives.

Get inspired, test our recipes either at workshops or chemistry labs, and develop your own experiments!

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