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Wood – a sustainable resource

EMPA
Materials Science & Technology

Research for medium-sized companies
Exhaust flow lab helps clean up diesel fumes 06

"Hands on wood" – for 75 years

This is how long Empa has been conducting wood research. Humanity, of course, has been using this versatile material for a little while longer. Amazing things have been built from it – such as the pile-dwellings from the Stone and Bronze Ages that are mainly found in the Alps or the recently discovered, nearly 4,500 years old "wooden twin" next to the famous circle of stones in Stonehenge. Other creations are more notorious, such as the Vasa, an impressive Swedish galleon from the time of the Thirty Years' War that failed to travel even one nautical mile on its maiden voyage in 1628 before a gust of wind caused it to capsize (without making any contact with the enemy). A fate that can hardly be attributed to the construction material.

Despite (or perhaps expressly because of) this long history, wood is a material with a bright future. This is reflected by the National Research Programme "Resource Wood" (NRP 66) that was launched at the beginning of the year and, with 18 million Swiss francs over five years, is one of the highest-funded NRPs ever. This comes at just the right time, since Swiss forests are underused and over-aged. What's more, wood is a renewable raw material that does not have to be imported. At the core of NRP 66 is the optimization of the value chain forest – wood – chemistry – energy as well as (in the long run) the replacement of the current petrochemistry with lignochemistry (from the Latin "lignum" for wood).

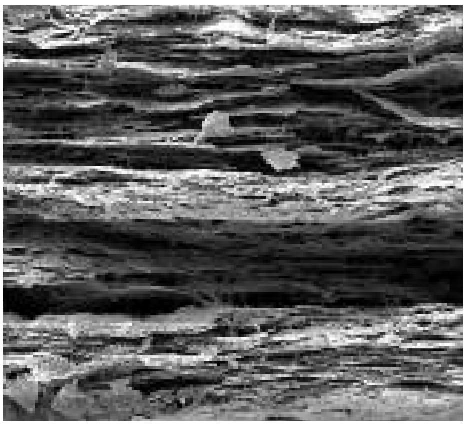
And in order to ensure that the acquired knowledge is also employed in practice as fast as possible, NRP 66 has joined forces with CTI, the Swiss government's innovation promotion agency. Companies, especially SMEs, as well as industry associations are welcome to join from the very beginning and should thus ensure an efficient knowledge and technology transfer. This is all very much in line with the spirit of Empa, upon whose initiative NRP 66 was created. The current "Focus" paints a portrait of the diverse research activities of Empa concerning the topic of wood.

Enjoy reading!

Michael Hagmann
Head Communications

Cover

Glued laminated wood, successfully patched with carbon fibres: Product engineer Annika Baier and Empa project leader Robert Widmann are delighted at the end of the hydraulic bending test. Engineering student Roman Frei feels the crack in the beam again.



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The garden hose fibre

Protective clothing is a must in many areas nowadays: be it in sport, for transport or in professions such as the police force and the fire brigade. However, the protection is often heavy and stiff, and restricts the wearer's freedom of movement. A research team at Empa is developing a fibre that does not hinder slow movements, but stiffens up quickly after sudden shifts in position or impacts, therefore providing the body with the necessary protection.

TEXT: Nicole Döbeli / PICTURES, ILLUSTRATION: Empa


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One possibility would be to design the safety clothing of the future like a warm chocolate cake: firm on the outside yet soft on the inside. Or like a cough sweet with a soft, syrupy core. This is exactly what Empa researcher Rudolf Hufenus is trying to come up with. Not for anything to eat, however, but in the form of a very special type of fibre. Its liquid core consists of a unique fluid that is soft or hard, depending on requirements: It remains liquid when stress levels are low, but becomes as hard as rubber when force is suddenly applied. Substances like this, known as dilatant fluids, are the key for Hufenus' project.

The basic idea of the "Rheocore" project that is being funded by the Swiss National Science Foundation is to spin a hollow polymer fiber containing a dilatant fluid. If the filament kinks or bends, the fluid inside is squeezed through narrow passages in the fibre's interior channels. The dilatant fluid reacts to this sudden shearing force and hardens, which stiffens the filament and confines the movement. However, slow movements are still possible because the filling maintains its low viscosity. Hufenus wants to use this feature to develop a fibre that will react dynamically to stress.

The idea of using dilatant fluids in textiles is nothing new. For instance, there is motor cycle clothing impregnated with dilatant fluids that stiffens in the event of an accident. The fluids are also contained within foam pads. Other examples are closer to home, for instance playthings such as "Silly Putty" found in many a child's playroom. This silicone-based material looks and behaves like plasticine as long as you work it slowly. But if you let it fall to the ground it bounces back like a rubber ball.

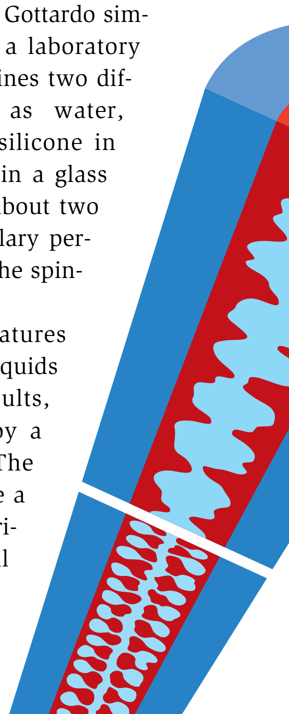
Liquid core

No one, though, has dared to try this on fibres yet. To begin with, there's the question of how you would even go about producing such a filament. Hufenus turned to melt-spinning technology. Plastic granules are filled into an extruder – a kind of worm drive that heats, liquefies and pushes the granules forward at the same time. A liquid plastic such as polyester is extruded through a spinning nozzle at the end of the tube, and can then be wound up and cooled. The pilot system in the "Advanced Fibres" laboratory even has two extruders. With them core-sheath filaments can be spun from two different polymers.

But how do you make a fibre with a hollow core? And how do you then fill it with a dilatant fluid? The pilot system at Empa was not designed for this type of experiment: the pressure in the spinning head can be 100 bar or more, and the temperature in the extruder up to 350 degrees C. Also, the metal housing conceals what is going on inside, which makes it impossible to develop a completely new spinning process.

Thus the researchers needed a laboratory model to gain a deeper understanding of the processes involved in the manufacture of a "fibre with filling". Unlike a garden hose, which you can simply connect to a tap, it is virtually impossible to fill the fibre with a liquid after it has been spun. Therefore, the liquid core has to exit from the spinning nozzle along with the solid polymer sheath, and the required cavity structure must also be created at the same time. Empa researcher Laura Gottardo simulates this process in a laboratory experiment. She combines two different liquids such as water, ethanol, Vaseline or silicone in various combinations in a glass tube at a pressure of about two bar, and a metal capillary performs the function of the spinning nozzle.

The different features and viscosities of the liquids yield different results, which are recorded by a high-speed camera. The difficulty is to generate a cavity with an appropriate shape. Individual separated drops do not



1
Empa researcher Laura Gottardo simulates how the fibres can be filled with liquid in a glass tube. The aim is to produce a string of connected droplets.

2
This is what the cross-section of the fibre should look like: an irregular cavity runs through the entire fibre and contains a dilatant liquid. Extremely fast movement makes the liquid harder and stiffens the structure. However, with slow movements the fibre remains pliable.

Video:
Hightech-textiles for hiking

http://www.empa.ch/EN36-1
For smartphone users: scan the QR code (e.g. with the "scanlife" app)

work, because the dilatant fluid cannot be displaced when the fibre is subjected to load; the cavity must therefore run continuously through the entire fibre, much like a cave system. However, even connected chambers in the form of a "pearl necklace" are of no use, since the shape is too regular. Cavities that narrow and expand at irregular intervals are ideal – this is the only way to generate shearing forces in the fluid and use them to stiffen the fibres.

It was the old saying "one man's curse is another man's blessing" that inspired the researchers to try something new: drilling holes in the metal capillary. This brought about turbulence between the sheath and the core fluid – precisely the thing you'd have to avoid at all cost in "normal" melt spinning.

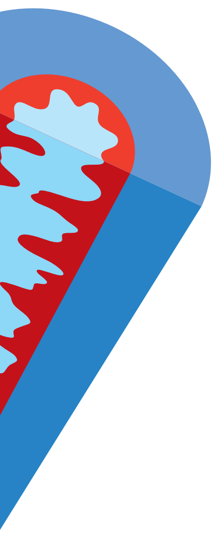
"Organ pipe" concept

The researchers derived the concept from organ pipes: "Organ pipes also need a hole to generate vibration and produce a sound", explained Hufenus. Thanks to this trick, it is now possible to produce the required irregular cavities in Gottardo's laboratory model. However, this doesn't make the project any simpler. The geometric shapes that are created are more than complex, and the turbulence can cause the filament to break.

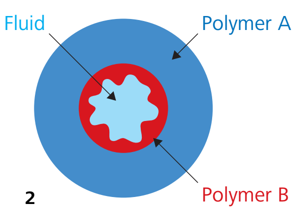
Holes seem to be the way to go, also in real spinning nozzles with hot, melted plastic. Instead of a single hole in the nozzle, Gottardo experimented with several holes of different sizes. She observed, for instance, that small holes create a continuous flow of the core fluid, whereas larger holes have a tendency to cause droplet formation. If a nozzle has a small hole in the centre and bigger holes around it, the droplets from the large holes "interfere" with the continuous flow of liquid from the small hole. This creates instability in the flow, which can be used to structure the cavities.

But since the laboratory model cannot be transferred one-to-one to the extruder, the researchers will first have to simulate the processes in the extruder. Hufenus: "We will be flying blind, because we cannot observe what happens inside". Marco Dressler from the University of Massachusetts is in charge of the calculations. He is going to create numeric models of the tests on a mainframe using the OpenFOAM software. Because of the complexity of the tests, it will take a good 24 hours to perform the calculations for four seconds' worth of melt spinning the "filled fibre" – with eight processors.

The "Rheocore" project should come to a closure in 18 months' time. By then the team wants to have worked out the basics for a more advanced industrial project. Exactly how the fibres will ultimately be used is still open and depends on future industrial partners. Be it protective or sports clothing or even medical applications – Hufenus and Co. are convinced that the potential is tremendous. //



Fibre Cross Section



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Operation Cleanup

In Empa's "Combustion Engines" laboratory, a team is working on the diesel exhaust cleaning system of the future. This is because diesel engines will still be with us for decades to come – in heavy trucks, construction machinery, commercial vehicles and the like. To clean diesel exhaust more efficiently, the researchers are developing nothing less than underhood "chemical mini plants".

TEXT: Rainer Klose / PICTURE: Empa

The heart of the exhaust laboratory is the glass test chamber, illuminated with red and green laser light.

The pipe that will be used in a few months' time to demonstrate whether and how diesel exhaust can be cleaned more efficiently is still cold. However, the electric heater has already completed its trial run up to 500 degrees C. The optical measuring devices, the high-speed camera and the pulsed laser are at the ready. Measuring can begin.

Switzerland's only exhaust laboratory is going to help to comply with diesel exhaust limits, which are going to become more stringent over the next few years. The results will mainly be useful to medium-sized vehicle manufacturers in the municipal vehicle area or the construction machinery industry, for example. But the majority of people who read this article and breathe in air at the side of a road or next to a construction site in 15 to 20 years from now will also reap the benefits. As little soot, nitrogen oxide and acrid-smelling ammonia as possible should be released into the environment when trucks (which will continue to use diesel engines in the future) are shooting past or construction machinery is operating. Besides, the machinery should also consume as little fuel as possible.

This requires quite a number of chemical tricks. The "small chemical plant" that filters and detoxicates the exhaust in modern trucks will have to become even more complex in the years to come. What's more, complex exhaust treatment systems that today are only found in heavy trucks are going to be installed in tractors and construction machinery at a later date as well. Thus, solutions that are both technically efficient and cost-effective are required if a manufacturer wishes to compete on the global market. And Empa helps to deliver.

Diesel exhaust contains a mixed bag of nitrogen oxides, collectively called NO_x. These are unavoidable in combustion processes at high temperatures. Conventional catalytic converters such as the ones used in petrol engines cannot reduce NO_x, which are responsible for the formation of smog, irritate the respiratory tract and form nitric acid in combination with water.

The nitrous oxides are removed by means of reduction. Small diesel engines in passenger cars use a NO_x storage catalytic converter, which collects the NO_x and has to be "emptied" every now and so often. To do this, the engine runs "rich" for about ten seconds every two minutes. More diesel fuel is injected, and the non-combusted carbon in the fuel reduces the NO_x into harmless nitrogen and water vapour. Advantage: cleaner exhaust. Disadvantage: higher fuel consumption.

Adblue cuts consumption

However, additional fuel consumption in their vehicles is a thorn in the side of haulier companies. They are placing their bets on a different solution: urea injection. Urea dissolved in water, which is marketed under the trade name of "Adblue" in Europe and the USA, is injected into the hot exhaust. The urea breaks down into CO_2 and ammonia – and this in turn can reduce NO_x. Advantage: no increase in fuel consumption.

However, even this solution has a drawback: if you inject too little Adblue into the exhaust, only part of the nitrogen oxides is destroyed. If too much Adblue is injected, ammonia remains – which is less than desirable due to its pungent smell

Video:
Engine lab for ecological drivetrains

http://www.empa.ch/EN36-2
For smartphone users: scan the QR code (e.g. with the "scanlife" app)

and toxicity. The latest exhaust gas cleaning systems therefore operate on the "safe side": only about 60 per cent of the required quantity of Adblue is injected to avoid stench at all costs.

This is where the Empa exhaust gas laboratory comes in – a ten-meter installation on the second floor of the Empa engine building. The intention is to perform several series of tests in order to investigate how the Adblue solution can be mixed with the exhaust as efficiently as possible, how much Adblue one would have to add (depending on the engine operating load) and how emissions can be optimised with the least technical effort.

Experiments with "simulated" exhaust

The researchers in the Empa "Combustion Engines" laboratory want to tackle the problem in individual stages. Firstly they will examine different injection nozzles. The nozzles will be suspended in a glass chamber, which will be flushed with compressed air at up to 500 degrees C. A high-speed camera will then record how the injected additive is distributed in this "simulated" exhaust. Even the speed and path of individual droplets can be documented at 10,000 pictures per second. The analytic methods that will be used are known as shadowgraphy, Schlieren imaging, PIV (Particle Image Velocimetry) and PDA (Phase Doppler Anemometry).

In the first six to nine months, project leader Dimopoulos Eggenschwiler and his Ph.D. student Alexander Spiteri primarily want to concern themselves with spray and fluid dynamics. Their goal is to work out a scientific system that will allow small and medium-sized vehicle and construction machinery manufacturers to design an exhaust cleaning system "from a recipe book", as it were, that best suits their own engines and requirements. This is the only way to comply with future exhaust gas limits.

In the second phase the researchers will determine the location in the exhaust system, at which an Adblue injection is most effective. Besides the order of the cleaning stages, the size of both the hydrolysis catalytic converter (in which Adblue breaks down into ammonia) and the SCR catalytic converter (in which the ammonia reacts with the nitrous oxide) are crucial parameters to be investigated. And finally the Empa researchers are still looking for the best possible precious metal to put into the catalytic converter.

In the final stage of the project, various "diesel catalytic converter" configurations will be tested in more detail. Whereas initial tests are run with hot air or artificially generated gas mixtures, a commercially available diesel engine will now be used to ensure the "prototypes" are tested under real-world conditions. A Swiss construction machinery manufacturer has already teamed up with Empa, and hopes to benefit from the experience.

Nobody needs to worry, though, about thick clouds of exhaust coming out of the Empa engine building. The tests are only run for a few hours. At most, the total exhaust corresponds to that of one additional truck on the Überlandstrasse – a four-lane motorway running past the Empa campus in Dübendorf. However, the knowhow to be gained will help us all to reduce the exhaust burden in the years to come. //

New insights from old samples

Alfred Werner, who later won the Nobel Prize, created the basis for modern complex chemistry in 1893 – without a single experiment. But proving his theory turned out to be laborious and time-consuming – apparently because Werner overlooked an important aspect of crystallisation. X-ray analyses carried out by researchers from Empa and the University of Zurich on salt crystals produced by Werner's team have now refuted this school of thought.

TEXT: Nina Baiker / PICTURES: Empa

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1
Laboratory notes from Nobel Prize winner Alfred Werner.

2
Metal complex salts more than 100 years old.

3
The crystals that Werner and his co-workers grew did not provide proof of chirality (handedness): Left-handed and right-handed forms are both contained in one crystal.

For Empa chemist Karl-Heinz Ernst, it is (almost) all about stereochemistry, i.e. the three-dimensional structure of molecules. "The spatial arrangement of atoms in molecules is decisive for the chemical, physical and biochemical characteristics of a compound", he explains. For example, the structure of proteins influences their functionality in the organism, as is the case with enzymes. Ernst is mainly interested in a particular aspect of the spatial structure, the chirality or handedness. If two molecules that are otherwise identical behave like mirror images (like our hands), the compound is known as chiral.

Chirality as the focal point of science and the world market

Many pharmaceuticals, fragrances, pesticides and fine chemicals are chiral – and are researched intensively. Global sales of chiral drugs of about 40 billion US dollars in the mid-1990s have now more than quintupled.

3

In order to manufacture chiral compounds on an industrial basis, catalytic procedures are used that selectively only produce one enantiomer, i.e. one mirror image form of the molecule, but not its “twin sibling”.

New research results and developments in the area of stereochemistry are presented annually at the “International Symposium on Chirality”. Several years ago, as a participant, Ernst put a question to his colleagues that he considered to be quite simple – and did not receive an answer: “How did Alfred Werner actually prove his theory on the spatial structure of inorganic complex compounds?” Ernst therefore decided to reconstruct the history of the proof and stumbled upon an amazing discovery.

Alfred Werner (1866–1919) is considered the founder of modern complex chemistry. In 1893, he was the first to formulate a well thought-out coordination theory (which was contrary to the school of thought at the time), which still forms the basis of complex chemistry today. Until then, metal complexes were drawn on paper as aliphatic compounds. Werner wrote off colleagues who acted this way as “Stichchemiker” (graphic chemists). He, on the other hand, arranged chemical groups spatially around a central metal atom and was thus able to predict new compounds. This spatial arrangement also hinted at the possibility that metal complexes might be chiral. However, it took him another 18 years before he was able to prove his theory. He was awarded the Nobel Prize for chemistry for his proof in 1913.

Alfred Werner’s “ingenious impertinence”

The chemists of the 19th century who were interested in metal salts were fascinated by their wealth of colours. Educated in organic structural chemistry, in 1893 Werner turned the prevailing idea of the structure of these compounds on its head in his work “Beiträge zur Konstitution anorganischer Verbindungen”. Werner’s “knowledge” was

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1
Nobel Prize winner Alfred Werner: like Kekulé, the solution to the problem appeared to him in a dream.

2
Ph.D. student Victor King separated the left and right hand enantiomers in 1911. This cleared the way to Werner's Nobel Prize.

completely based on theoretical considerations; he had not carried out a single experiment. Similarly to August Kekulé with benzene, the solution "appeared" to Werner in a dream, which he then wrote down in the middle of the night. An "ingenious impertinence", as was appropriately formulated by a colleague at the time.

In the following years, Werner synthesised a large number of the metal complexes that he had postulated. These results spoke in favour of his theory but did not prove it. This did not occur until 1911, when Werner's Ph.D. student Victor King succeeded in separating the left and right mirror image forms after more than 2000 failed attempts – therefore experimentally proving the handedness of a chiral metal complex. As the method of proof he used polarimetry, i.e. the rotation of light's plane of polarisation. His colleagues therefore frequently greeted him in the pubs of Zurich with: "Is it rotating yet?"

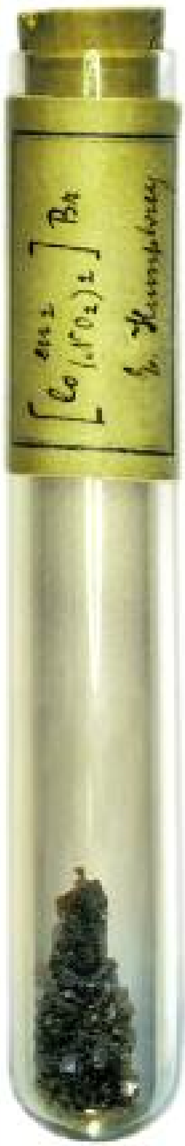
According to the current school of thought, Werner could have proved his theory much sooner if he had just examined individual crystals of another Ph.D. student of his, Edith Humphrey, since these were said to have split up by themselves into left and right handed crystals. Even though it was more of an exception, it was already known that some chiral compounds split up "on their own" during crystallisation, and individual crystals only contained right or left handed molecules. Stereochemistry had already been launched by Louis Pasteur 50 years earlier by separating tartaric acid into the two enantiomer forms using this method.

Humphrey had been dealing with chiral metal complexes since 1898. Even so, she and Werner obviously never examined the crystals closely enough for their handedness. Werner himself, though, had taken the possible self-splitting of chiral compounds into consideration back in 1899, and discussed it in a publication. The "victim" of the long drawn-out verification procedure was Werner himself; the analytical chemist was nominated for the Nobel Price every single year from 1907 on. However, it was not until he was able to experimentally verify the chirality of various complexes that the theory was generally accepted, and he finally was awarded the Nobel Prize for chemistry six years later.

New insights from old samples

In a paper recently published in "Applied Chemistry", Karl-Heinz Ernst now came to the conclusion that Werner could not have proved his theory without further ado on the basis of Humphrey's samples. For two years, Ernst had immersed himself in the work of Werner and his colleagues in his spare time. With colleagues from the University of Zurich Ernst even carried out X-ray structural analyses on original samples more than 100 years old – and made some completely new discoveries about the structure of the crystals that Werner's team had produced.

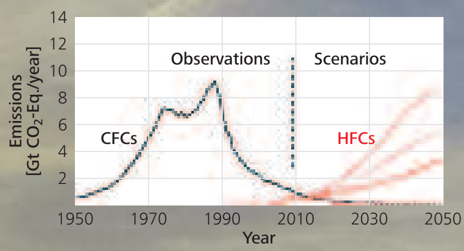
The analysis of Ellen Humphrey's crystals revealed that they had not separated themselves into left and right handed forms. Only very few (and extremely tiny) crystals had accumulated one mirror image form over the other. In other words: If Humphrey had examined large crystals for chirality, the result would have been negative. Ernst proved that the crystals are so-called twins, containing left and right handed forms, with a sandwich structure. The school of thought with regard to the self-splitting of chiral compounds will thus have to be revised, at least as far as Humphrey's samples are concerned. //

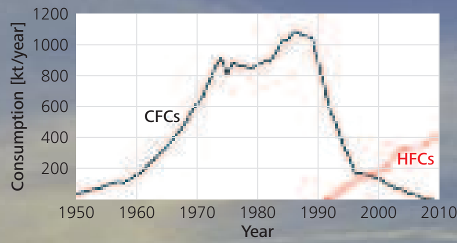


Cooling agents heat up climate

The Montreal Protocol led to a global phase-out of substances that deplete the ozone layer, such as chlorofluorocarbons (CFCs). But their substitutes, Hydrofluorocarbons (HFCs), are climatically very active and many are also extremely long-lived. In the renowned journal “Science” an international team of researchers recommends that the most potent of these gases also be regulated.

TEXT: Michael Hagmann / PICTURE, ILLUSTRATION: Empa





It is regarded as the most successful international environmental agreement and has been ratified by 196 countries – the Montreal Protocol on Substances That Deplete the Ozone Layer. As a result, CFCs and ozone “killers” will gradually disappear from the atmosphere over the coming decades. And because many of these substances are also very active greenhouse gases, the Earth’s climate will profit too.

So far, so good. In many processes where previously CFCs were used, these are now being substituted by fluorinated compounds such as HFCs (which, simply put, are similar substances to CFCs but do not contain chlorine and do not deplete stratospheric ozone). They are used as cooling agents in air conditioning plants and refrigerators, as propellants in aerosol cans, as solvents and as foaming agents in the manufacture of foam products. However, there is a downside to the use of HFCs – they are also very potent greenhouse gases. HFC-134a, also known as R-134a, for example, which is used in automobile air conditioning units, is 1,430 more active than the “classic” greenhouse gas carbon dioxide (CO_2).

Equivalent of ten billion tonnes of CO_2

The significant increase in global emissions of HFCs seen over the past few years will soon negate the positive effects on climate brought by the Montreal protocol’s CFC phase-out.

This link is shown by an analysis published in by the magazine “Science” in its February issue. An international team of researchers, headed by Holland’s Guus Velders and including Empa researcher Stefan Reimann, investigated the unintentional (positive) climate effects resulting from the Montreal Protocol: the CFC ban has prevented the equivalent of ten billion tonnes of CO_2 being emitted into the atmosphere in 2010, five times the annual reduction target set by the Kyoto Protocol.

Velders, Reimann and their co-authors fear that this positive effect will soon be negated by HFC emissions, which are currently increasing at 10 to 15 per cent annually. In their article they state that “the HFC contribution to climate change can be viewed as an unintended negative side effect” of the Montreal Protocol. The greatest problem, according to the scientists, is presented by saturated HFCs, which are extremely stable and survive in the atmosphere for up to 50 years, exhibiting a long-term global warming potential of up to 4,000 times higher than CO_2. For Empa researcher Reimann the situation is clear: “Long-lived HFCs should no longer be used in these quantities.”

A “simple” solution: expanding the scope of the Montreal Protocol

Among other things, the scientists recommend modifying the Montreal protocol so that it also covers the use of long-lived HFCs. “Since it is it is as a result of the Montreal protocol that these substances are being manufactured in increasing amounts, they could be included in the agreement too, so their use can be regulated as well”, maintains Reimann. //

Wheelchair ergonomics

People who depend on a wheelchair usually have problems because they are always sitting in the same position. This can lead to pain, deformities and sores (decubitus). Engineer and ergotherapist Roger Hochstrasser, founder of *r going*, wanted to help. Together with Empa researchers, he developed new seats for improving wheelchair ergonomics and therefore avoiding additional therapy costs. The project was funded by CTI, the Swiss innovation promotion agency.

TEXT Martina Peter / PICTURES: Empa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1
The moving, programmable backrest, with which an ergotherapist can change wheelchair posture.

2
Test drive with a prototype of the new wheelchair.

The new seat has a moving backrest consisting of rib and joint elements that simulate the structure of a human torso. Researchers from the Institute for Energy and Mobility (IEM) at the University of Berne developed the drive concept and control console, which allows the ergotherapist to program the backrest movements so that the sitting posture of the wheelchair user is altered in an optimal fashion. Depending on the "model", the backrest can be tilted up to 22 degrees forwards and 40 degrees backwards, it can be rotated horizontally by a good 30 degrees in each direction and therefore "forces" the person in the wheelchair to change their sitting position and relocate the pressure points, as measurements with a pressure mat on the seat have shown. "If someone happens to feel uncomfortable, the presettings can be modified individually at any time", explains Empa project leader Bernhard Weisse. Extremely practical: the 24-volt battery that supplies the wheelchair with energy also moves the backrest.

Empa wouldn't be Empa if it hadn't given the new development a comprehensive practical test. Test users of different weights drove the prototype over pebble paths, up and down ramps, over kerbstones and cobbled roads. A winding road trip with the Tixi-Taxi, the transport service for handicapped persons, served to evaluate the load on the backrest – all to the complete satisfaction of Hochstrasser and Weisse.

Clinical studies will be commencing soon. These will show whether the pressure values measured in the laboratory actually do improve the well-being and health of handicapped persons, and whether they accept the innovation. //

While you were sleeping

In May a monitoring system is becoming commercially available that will allow nursing staff to accurately record the mobility of bedridden persons. The system has been developed for the prevention of bedsores by *Compliant Concept*, a start-up at Empa's glaTec technology center.

TEXT Martina Peter / PICTURE: Empa

The motion sensor is suspended from the edge of the bed and records whether the patient has changed position during the night. The measurements can also be analysed on the computer.

Healthy people move an average of two to four times per hour in their sleep. The movements are triggered by pain that occurs when tissue has an insufficient blood supply. The sleeping person changes position involuntarily, relieves the pressure point and therefore prevents bedsores, which are known in professional jargon as "decubitus ulcers".

However, the decubitus prophylaxis that is "built in" by nature does not work in people with paralysis and patients who are sedated, unconscious or suffering from a high fever. The lack of movement means that parts of the body remain under pressure for too long, and the microcirculation is interrupted. If this persists for too long, it can result in a painful bedsore.

In order to prevent this, bedridden patients must be moved at regular intervals. Compliant Concept, a spin-off of Empa and ETH Zurich, has developed a "Mobility Monitor" that alerts nursing staff when it is time to reposition a patient. The system assesses and records the mobility of a bedridden person. "The monitoring system is part of our concept for decubitus prophylaxis", says Michael Sauter, the founder of the company, who collaborated with doctors and care experts to develop the system. His goal is an entire hospital bed system that imitates the movements of a healthy person during sleep and therefore continuously and gently moves the patients.

The measuring unit of the new system is installed beneath the mattress and connected to the display unit at the edge of the bed as well as to the light-signaling system. The monitor uses a traffic light system to show how mobile the patient is at any given time, and therefore provides valuable information that helps nursing staff to correctly estimate the risk of decubitus, and therefore reduces unnecessary physical effort. The system also reminds the personnel when the next movement is due and issues a warning if too much time has gone by since the last movement.

Successful in numerous tests

"The nursing staff are often unsure whether the patients need to be moved at all. They cannot stand at the bedside all the time to observe movements", emphasizes Sauter. "Particularly during the night, it would be better if the patients' sleep did not have to be disturbed unnecessarily". In the last few months the new system has proved itself to be extremely useful in numerous tests in care homes and hospitals. The "Mobility Monitor" will be available on the Swiss market as of May. Until then it can be purchased directly from Compliant Concept.

Financing for further projects relating to the "intelligent" hospital bed, for which the fledgling company has already received several awards, has been secured until the end of the year. Until then Sauter wants to obtain additional capital for the company by means of another round of financing so that the product can be launched internationally over the next few years. //

More at: *www.compliant-concept.ch*

MODULE 6

Recycling, reuse and disposal
What's the best way of recycling wood biologically? Which environmental problems does society have to keep in mind as the use of wood increases? (ETH Zurich, EPF Lausanne).

MODULE 5

Wood in a "supporting" role
Can beech be used as a building material? How can multi-storey wooden houses be soundproofed to prevent footfall noise? How resistant to earthquakes are they? Can wooden houses be assembled by robots? (Empa, ETH Zurich, University of West Switzerland)

MODULE 4

Components made of wood
New adhesives and manufacturing methods for laminated wood and plywood are intended to make wood components better and more popular. Novel protective coatings and natural protective layers improve the material's durability. (Empa, ETH Zurich, University of Berne, Université de Fribourg)

Wood – sustainable resource with a bright future

The National Research Program “Resource Wood” (NRP 66)

Ten million cubic metres of wood grow in Switzerland every year, but only two thirds of it are utilised. The Swiss forest is expanding and getting older.

The National Research Program 66 is intended to increase the demand for domestic wood and develop innovative ways of adding economic value. There is a surplus of Swiss wood – and it can be a substitute for crude oil.

NRP 66 was instigated by the Swiss government in 2010. Research projects started in January 2012.

MODULE 1

The source material: raw timber
Where and when can wood best be harvested in Switzerland? (Swiss Federal Institute for Forest, Snow and Landscape Research, WSL)

MODULE 2

A commodity for the chemical industry
Lignin, a major wood constituent, can be the starting point for many chemical substances. Waste wood could also be used for this purpose. (EPF Lausanne, ETH Zurich, PSI, various universities of applied sciences)

MODULE 3

A renewable energy source
Wood furnaces? That was yesterday’s thing. Research is now focussing on purified wood gas, bio-methane and high-purity hydrogen produced from wood. (PSI, ETH Zurich, Lucerne University of Applied Sciences and Arts)

Video:
Wood research at Empa

http://www.empa.ch/EN36-3
For smartphone users: scan the QR code (e.g. with the “scanlife” app)

Boulevard of broken beams

How can professional repairs be made to cracks in support beams? Is it better to use screws or carbon fibre mats? And: how much strain can the fixed component still withstand? Empa engineers seek and find answers.

TEXT: Rainer Klose / PICTURE: Empa

A technician reinforces the broken wooden support with carbon fibre mats and epoxy resin. The sample is left to dry for one week, then its load-bearing capacity is tested in the hydraulic press.

With all due respect, project leader Robert Widmann from the "Structural Engineering" laboratory and Roman Frei, student at the Berne University of Applied Sciences, keep their distance to the hydraulic press in Empa's engineering and construction hall. A beam made from glued laminated wood, consisting of 13 layers of spruce and two layers of ash, is being "tortured" to death. The beam bends silently, accompanied by the humming of the hydraulic pump. Then, at a load of 430,000 newtons, corresponding to a weight of 43 tonnes, the component breaks with a muffled, dry crack.

Instantly Roman Frei reaches for the crank handle of the hydraulic press and reduces the oil pressure. Both scientists spotted the millimeter-thin crack that occurred from afar. Now they move closer to the broken beam and examine what has happened.

The "tortured" beam is part of a series of tests within a research project funded by the Federal Office for the Environment (FOEN) for a "practice-oriented survey and reinforcement of components made from glued laminated wood". In other words: the idea is to compare different reinforcement methods that can be used on cracked support beams. You can screw the crack together,

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Now it gets serious: project manager Robert Widmann (left) monitors the three-point bending test on the carbon-reinforced wooden support. Engineering student Roman Frei (far right) operates the hydraulic press. At a load of 43 tonnes the laminated wood support breaks with a dull crack, and the displacement is measured. One can monitor where and when the break occurred on the computer screen.

glue it or stick a “plaster” made of carbon fibre around the damaged component. This method is frequently used on damaged concrete supports. But would it also work with wood?

The sorry test beam was prepared meticulously for its date with destiny: the Empa researchers deliberately introduced a material fault when they glued the individual boards together. Glue was only applied to one-third of the contact surface of the middle layers. The intention was for the beam to break at this soft spot and then be repaired in order to prove the effectiveness of the repair method in subsequent tests. All in all, there would be eight of these tests, evaluating four different repair methods: one, two or four fully-threaded screws per breaking point and carbon fibre mats glued around it with epoxy resin.

The result even surprised the experts: with just a single screw per breaking point, the glued laminated wood beams withstood a higher load than in the non-reinforced condition. The repair method using carbon fibre mats was similarly effective. On the other hand, it is unnecessary to repair the beam with more than one screw per breaking point – this only makes the beam break in other locations, i.e. extra screws do not provide additional reinforcement. In order to document the experiments the broken beam will then be X-rayed. Many beams are even cut open and assessed on the basis of the individual components. Wood construction companies all over the country will benefit from this new knowledge, and will be able to make repairs to support structures more efficiently in future. //

"Wood has many advantages."

Ingo Burgert was appointed Professor of Wood-based Materials at the ETH Zurich in October of last year; the 43-year-old also manages the research group for "Bio-inspired Wood Materials" at Empa. In a conversation with EmpaNews he explains the goals he is pursuing.

Interview: Rainer Klose / PICTURE: Empa

Mr Burgert, what qualifications do you need to become Professor of Wood-based Materials?

Ingo Burgert: you can start with studying wood science and then do a doctorate. In my case this was at the University of Hamburg.

What was the topic of your doctorate?

I wrote a thesis on the mechanism of wood rays in trees. These are the structures that run radially along the cross-section of the wood and therefore look like the spokes of a wheel. I examined the mechanical properties of the wood rays and how they contribute to maintaining the stability of the tree.

Wood is a material that has been used and studied for a long time. Isn't it difficult to obtain new knowledge about this well-known material?

Wood is a biological material and therefore has a hierarchical structure. This means that the nanostructures and microstructures of wood are decisive for its macroscopic characteristics. The im-

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portant element that controls the characteristics in large structures can be found in the small, the cell wall structure. We are now in a better position to examine the nanostructure and the microstructure in much greater detail, and even characterise it mechanically. In this way, we can obtain new knowledge of the basic mechanisms and structural parameters that determine the properties of wood.

Where is your research going to take you? What do you want to do?

Wood has many advantages. Considering its low density, it has extremely good mechanical properties. However, it also has typical disadvantages such as its combustibility and the problem of expansion and contraction. We want to go down different routes with our research in order to minimise expansion and contraction, and thus make wood more "dimensionally stable". Another topic is durability. Wood from some types of tree is durable, wood from other types much less so. We want to discover how greater durability can be "built into" the wood. The nano- and microstructure play a major part in all of these questions, since the characteristics of the wood cell walls determine the behaviour of the material.

Are you saying that wood does not just have to be examined superficially, but that you have to go deep into the structure?

Correct. The question is: in addition to existing methods, what ways are there of efficiently modifying the cell wall so that it binds less water? Because this is ultimately responsible for the expansion and contraction of wood.

Which types of wood do you start doing research with? Or doesn't this matter at all?

Now we are talking about the designation of my working group, "Bio-inspired Wood Materials". We can learn a great deal from nature about these matters: many types of tree such as oak or robinia form real heartwood, which can make the wood significantly more durable. Heartwood formation takes place after the fibres of the wood have long since died off, and are fulfilling their strengthening function in the tree. It is, therefore, possible for the tree to make belated chemical modifications to its wood. Of course, the tree is not trying to make the wood more usable for our construction projects – on the contrary, heartwood in the tree is used for depositing metabolic products. But we can learn from the underlying mechanisms.

If we now want to bring about this process artificially, we would have to three-dimensionally penetrate the wood structure – i.e. make use of the supply lines of the tree. How is that possible?

Making use of the supply lines of the tree is problematic, since these are only functional to a limited extent after the tree has been felled. We will therefore not be in a position to deal with wood elements with large cross-sections. However, we can modify wood with a small diameter and then create bigger elements by gluing these parts together. The latter is a normal procedure during wood production.

If I understand you correctly, are you saying that you are a kind of microstructural engineer for wood looking for the adequate chemistry to replicate such structures?

I look at nature and think about what I can learn from it. This may or may not be simply copying. On the contrary, we must understand the principles in order to utilise them to modify the microstructure and the chemistry of the cell walls. I will therefore gear up my team with suitable specialists such as polymer chemists. My working groups have always been extremely interdisciplinary. For our work you need expertise in wood science, biology, chemistry, physics and material sciences. You also need methodical ability in order to analyse the nanostructure and the mechanisms at a cellular level. We would like to carry out basic research to broaden our understanding of general principles, and at the same time develop novel wood products by making use of the acquired knowledge and ideas.

Speaking of methods: how will you examine the nanostructure of wood?

Besides electron microscopy we use spectroscopy, scattered X-ray methods and nanochemical and micromechanical characterisation. When doing this it is important to examine the cell wall as an intact unit in spite of its complexity. When I examine isolated cell wall components that have been removed from the whole, I lose important structural information and therefore access to the structure and mechanics of the whole.

Biography Info

Ingo Burgert (43) is Professor for Wood-based Materials at the "Institute for Construction Materials" at the ETH Zurich and group leader in Empa's "Applied Wood Research" laboratory since 2011. He studied wood sciences at the University of Hamburg where he gained his Ph.D. in 2000. He then worked at the University of Natural Resources and Life Sciences (BOKU) in Vienna. Before joining Empa Burgert managed the Plant Biomechanics and Biomimetics group at the Max Planck Institute of Colloids and Interfaces in Potsdam.

How will you organise your team between ETH and Empa? A few employees over there, a few over here?

I would like to separate the activities as little as possible. There should be one team with two locations, not two separate groups, because I would lose some of the synergy I can achieve with the combination of Empa and ETH. My employees should therefore be flexible and not set themselves up at a desk in one or the other location, but move between Empa and ETH with a laptop at hand. After all, research lives from communicating and exchanging ideas and knowledge. I consider the fact that we can experience this in our daily work both with colleagues at Empa and with the research groups at ETH a unique opportunity.

“My employees should move between Empa and ETH with a laptop at hand.”

How do you interact with the other research groups of the “Applied Wood Research” laboratory at Empa?

There are many areas, in which we work together and can provide mutual support for each other. Here at Empa, the modification of wood is the prime topic. Tanja Zimmermann, the leader of the laboratory, is one of the leading experts in the area of nano-cellulose. There are a lot of synergies in the area of the nano- and microstructural characterisation of materials. Martin Arnold works on surface modification. He is very experienced in wood technology and will be an important partner when it comes to practical applications of our results. Francis Schwarze has a large amount of expertise in the area of wood decomposition by fungi, we will work closely together on questions such as how to make wood more accessible and easier to penetrate. He has fantastic opportunities to reactivate the original transport routes of trees. But there are also overlaps with groups in other labs, for instance with René Steiger in the “Structural Engineering” laboratory.

Now you’re really entering the realm of the macroscopic…

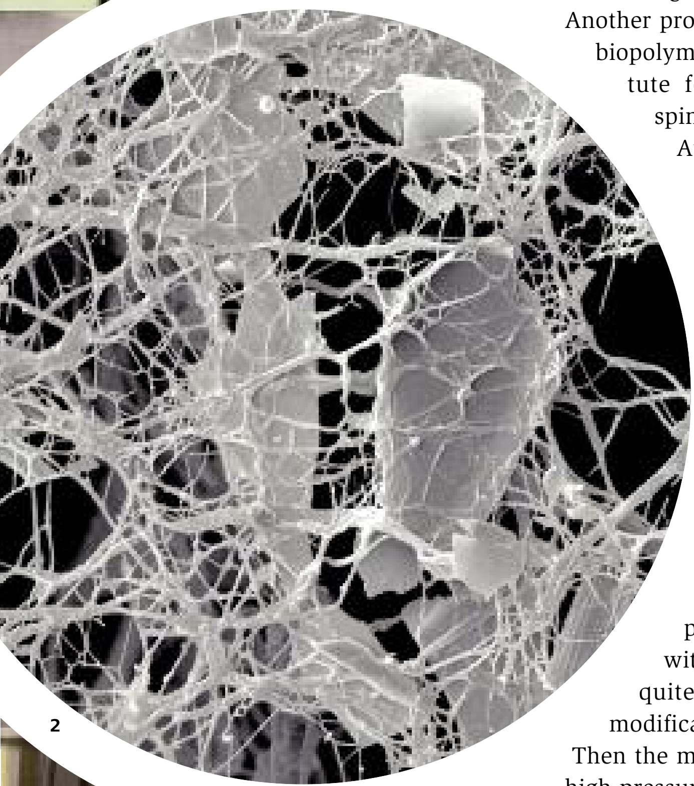
Yes, with wood components and entire buildings we’re actually closing the loop. Because eventually my work will also be measured against whether or not we are capable of transferring our nano- and microstructural modifications of wood into the macroscopic world. Improved properties, which only manifest themselves on a few cubic millimetres of wood, are not very interesting with regard to wood utilisation. With our research we want to lay the foundation for innovative wood products and contribute to adding economic value to this tremendously important natural resource. The prerequisites for this exciting task are ideal here at Empa and at the ETH Zurich. //

1

Wooden wonder from the pot

Can cellulose help to protect wooden surfaces from weather impacts? Empa is looking into this. But it doesn't stop there; this "wonder material" may soon also be used for spinal disc replacements, food packaging and filtering CO_2 out of the atmosphere.

TEXT: Rainer Klose / PICTURES: Empa



The secret of this material's success originates from a simple aluminium funnel containing cellulose soaked in water. From here, hoses lead to a high-pressure pump. In a brute force approach of sorts, the pump pushes cellulose fibres through thin, branched capillaries at pressures of up to 1,500 bar – an obstacle course made of solid steel. The delicate material comes off second best; the result is "nanofibrillated cellulose", in short NFC: tiny flakes of nanometre-thin fibres with amazing properties.

"We only need to stir one or two per cent by weight of NFC into water, and we already have a stable gel", explains Tanja Zimmermann, one of the leading NFC experts in the world, who has been dealing with this substance for about ten years. She has since tried out quite a few things with NFC. For example, the fibrils were used in collaboration with an industrial partner for reinforcing wood glue (polyvinyl acetate). Another project is investigating whether a biopolymer NFC gel is a suitable substitute for the jelly-like core of the spinal disc ("nucleus pulposus"). At Empa in St. Gallen, NFC-reinforced fibres have already been spun, and start-up company "Climeworks" extracts CO_2 from ambient air in a technically sophisticated way using NFC foam. In future, it may be possible to use the greenhouse gas to produce synthetic fuels.

Before too long, we might also encounter this wonder material in the fridge – it is under discussion as a barrier material for food packaging. "We mix the fibres with clay particles, which works quite well after a minor chemical modification", explains Zimmermann. Then the mixture is homogenised using a high-pressure procedure, compressed in a filter and hot-pressed. This produces a film that holds back water vapour and oxygen. "Our material could be used instead of aluminium foil, which is found in a lot of food packaging", hopes the Empa researcher. A big advantage of the NFC/clay film: it can be burned without problems and even composted, since the cellulose fibrils are biodegradable.

Now the researchers have set their sights on another potential application: improving coatings for wood protection. Can a substance that has been extracted from wood or straw indeed help to protect the surface of wood? Enter Martin Arnold, an expert in matters concerning the resistance and weathering of wood. Which constituents of the wood surface are attacked by the sun's UV rays? What happens to them? Is the decomposition product soluble in water, and is it washed out by rain? Arnold knows the answer. In the cellar of his lab he has a "weathering machine", in which wood samples are irradiated with UV light and rained on time and time again – an endurance test for wood and protective coatings. The effect of light is easy to be seen on any old piece of wooden furniture: "Dark wood becomes lighter in the light, but light wood becomes darker", explains Arnold.

Reinforced protective coating

A protective coating that is impervious to light helps to prevent this – but usually this alters the original colour of the wood. Arnold is familiar with the problem: "The more transparent the coating, the faster the protective effect abates. Nobody has solved this problem yet." As if this weren't enough there is yet another issue: the expansion and contraction of wood. Any coating that is to last for a number of years must flexibly adapt to the working wood. If the coating becomes brittle, it cracks – and the wood underneath is then exposed to rain and microbial attack.

The Empa researchers believe that NFC fibres can help with precisely these two issues as constituents of a protective coating. UV-absorbing substances, e.g. in the form of nanoparticles, could be embedded in the matrix of the cellulose fibres. And with the help of these fibre networks the substances would also be evenly distributed in the coating. The crack resistance of the NFC fibres that has already been demonstrated could also reinforce the coating and prevent cracking. The coating would thus have a better protection from hailstone impacts.

However, there are still many obstacles to overcome. For example, cellulose – which is inherently "water-friendly" – must be chemically modified so that it also disperses itself in "oily" wood protection coatings. Initial tests have been carried out since the beginning of the year within the scope of National Research Programme (NRP) 66 (see also pages 14 and 15). //

1
Cellulose is prepared for high-pressure treatment in this metal funnel. Tanja Zimmermann and Martin Arnold want to use this "wonder material" for improved wood coating.

2
Nano-fibrillated cellulose under the electron microscope: Clay particles are distributed in the filigree cellulose network in this sample. The clay forms minute "leaves" in the structure.

Biologically refined

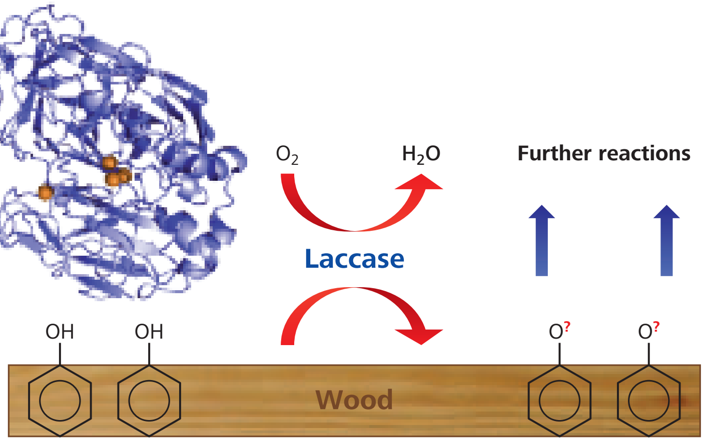
The surface of a piece of wood is full of biochemical “connectors”. A team at Empa considers this a perfect opportunity to outfit wood with exactly the features we would like it to have: surfaces that are easy to stick to, anti-fungal coatings – or even self-adhesive wood chips that can be compacted into fibre boards that are 100 per cent ecological, without any chemical additives whatsoever.

TEXT: Rainer Klose / PICTURES: Empa

1

1
Mark Schubert compares a sample of fungus-treated wood to a non-treated sample (right of picture). The fibre panel (big picture) he is holding can be manufactured without chemical adhesives – the wood is self-bonding.

2
Enzyme treatment: the laccase uses chemical “docking stations” on the surface of wood and thus makes the wood reactive.



2

Sometimes innovations start with a simple run through the woods: “One particularly good idea occurred to us when we were out jogging”, explains wood expert Mark Schubert from Empa’s “Applied Wood Materials” laboratory. Occasionally Schubert does a few laps in the woods with his colleague Julian Ihssen. The two of them set off one day, and Schubert had an unfinished project on his mind. This time they came back with a cracking idea: the vision of an antimicrobial wood surface.

But let’s not get ahead of ourselves: Schubert, who is a qualified forestry researcher and environmental scientist, initially studied ways of combating fungi that damage wood by other fungi. Then, for several years, he turned to using fungi to specifically modify the properties of wood. Currently, Schubert is working on certain enzymes from fungi that have specialised in “digesting” wood during the course of evolution. Laccase, for instance, which is produced by many white rot fungi, can modify the surface characteristics of wood: it converts some chemical sub-structures of lignin, a wood constituent, into radicals – making the surface of the wood reactive (see picture).

Herbal fungicide of ancient Egypt

But what can you do with a wood surface that is then “open to new ideas”, in a manner of speaking? Well, first, you could consider a wood preservative that can be firmly anchored to the surface and will give the bare wood better protection from decay. Schubert started to run tests with isoeugenol, an antioxidant, and thymol, a herbal fungicide, which were already used by the ancient Egyptians to preserve their mummies. But his initial attempts fell on stony ground – the substances were too easy to wash off or lost their antimicrobial punch in interaction with the enzyme.

Time to go for a jog, thought Schubert – which brings us back to the beginning of the story. Schubert told Ihssen, a researcher in the “Biomaterials” laboratory, about his difficulties – and got a straightforward recommendation: “Try an old home remedy”. The two of them gave it a go and actually succeeded with, of all things, a cheap substance that can be found in any medicine cabinet: the compound literally stuck to the surface of the wood. By way of a trial, Schubert and Ihssen treated test pieces of spruce with aggressive, wood-damaging fungi. Whereas the untreated test pieces had been eaten away deep into the wood after 12 weeks in the incubator, the treated test pieces had withstood the fungi. What the remedy is can’t be disclosed at this point, though – the researchers are considering patenting their discovery.

The experiment proved two things: laccase functionalised wood surface so profoundly that useful quantities of a desired substance can be chemically attached to it. And applying a cheap mass-produced medicine to the wood provides antiseptic properties that can be useful for many different applications. Just think about wooden components and furniture in public buildings or on public transport, in hospitals, kindergartens and restaurants.

Now Schubert is hoping to find an industrial partner who would be willing to develop this antimicrobial wood treatment to a stage where it can be marketed. He is also pursuing two other projects, for which the laccase modification has been the door opener: if wood stuck to adhesives more effectively, stronger glued connections would result – even between wood such as larch and beech, which have always been difficult to glue. In order to do this, the wood is pre-treated with aqueous laccase solution. Functional groups such as amines could then be attached as anchor molecules to the radicals that are produced. These anchor molecules can then chemically bind to the adhesive, making the connection significantly stronger.

Anyone who would rather stay clear of chemistry may prefer the third application for enzymatically treated wood – adhesive-free fibre boards. If pre-treated wood fibres are compacted, they can form chemical bonds with neighbouring wood fibres. There would thus be no need for chemical bonding agents such as resins or isocyanates in the manufacture of so-called medium density fibre boards. A chemical-free, ecologically harmless fibre product comes within reach.

Harmless to people

The use of laccases is nothing to worry about, explains Mark Schubert: the proteins are biologically degradable, they are harmless to people and animals and are also non-hazardous in case of skin contact. They perform their job on wood at room temperature – without using acids or alkalis beforehand. However, there is still a great deal of detail work to be done before enzymes really take off in industrial wood treatment. Not all variants of the laccase enzyme are equally suitable for all types of wood, and in order to find a suitable enzyme the enzymes must first be characterised and compared. Cost-effective and efficient manufacture of laccases from white rot fungi also has to be investigated further and optimised quite a bit. //

Venture kick: start-up money for artificial muscles

Compliant Transducer Systems GmbH (CTSystems), the start-up company established by Empa researcher Gabor Kovacs in August 2011, received 10,000 francs from the “venture kick” start-up foundation for its impressive business idea. Kovacs devotes himself to the mass production of artificial muscles, and his company is going to develop two production processes: a “stacker”, with which large quantities can be manufactured at low cost, and a “plotter”, which can manufacture extremely complex, fine structures for high-quality components (reported in issue 35 of EmpaNews in January 2012). For the first phase of the competition for start-up grants, Kovacs submitted a short profile of his company and convinced the “venture kick” jury of his business idea in a ten-minute presentation. The money is now going to be used to develop a web site and cover the cost of cooperation negotiations.

The money from the “venture kick” funding initiative originates from funds from the AVINA foundation, the Ernst Göhner foundation, foundation 1796, the Gebert Rüf foundation and the OPO foundation. Up to 130,000 francs per start-up project are distributed in several stages. Now that he has succeeded in obtaining the funds for the first level, Kovacs intends to apply for the next stages in the coming months: 20,000 francs for a “business case”, in which customers-to-be and strategic partners have to be identified, and finally 100,000 francs for successful start-ups. At this stage the team has been put together, the intellectual property has been protected and the company is ready for its market launch.

CTI: innovation program every 9th project goes to Empa

A flood of proposals for the Swiss government’s 100 million innovation programme to counter the strong Swiss franc hit CTI, the federal innovation promotion agency late last year. Up to the submission deadline on 15 December 2011 a total of 1,064 applications to the value of more than 530 million francs came in; 105 proposals were submitted by Empa researchers.

Eventually 246 projects were approved. With 27 funded projects Empa had a success rate of about 26 per cent. Grants to the value of 12.3 million francs will be winging their way to Empa’s Dübendorf, St. Gallen and Thun sites. The projects range from hybrid drives for municipal vehicles to climbing skins for backcountry skiing, and from quantum cascade lasers to new concrete concepts for prefabricated parts.

In late September 2011 the Swiss government and parliament launched a special programme to counter the effects of the strong franc in order to boost the competitiveness of the Swiss export industry. An additional 100 million francs were made available to the CTI for promoting innovation. The goal was to allow companies under margin pressure to quickly implement innovative projects in collaboration with research institutes, first and foremost projects with a rapid effect on the market or risky projects that companies have had to postpone due to dramatic margin erosion.

Events

16 – 20 April 2012
Intensive course: Nanopowders and Nanocomposites
Empa, Dübendorf

26/27 April 2012
3-Länder-Korrosionstag
Empa, Dübendorf

2 May 2012
Imaging and image analysis of porous materials
Empa, Dübendorf

23 – 25 May 2012
Fibre Society Conference 2012
Empa, St. Gallen

11 June 2012
Electrical Overstress (EOS) – das «unbekannte» Phänomen in Schaltungstechnik und Ausfallanalyse
Empa, Dübendorf

12/19/26 June 2012
Flottenmanagement ganzheitlich betrachtet
Empa, Dübendorf

13 June 2012
48th Discussion Forum Life Cycle Assessment: ecoinvent v3
Empa, Dübendorf

30 August 2012
Innovation Day 2012 (Textil und Bekleidung)
Empa, Dübendorf

Details and additional events at
www.empa-akademie.ch

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