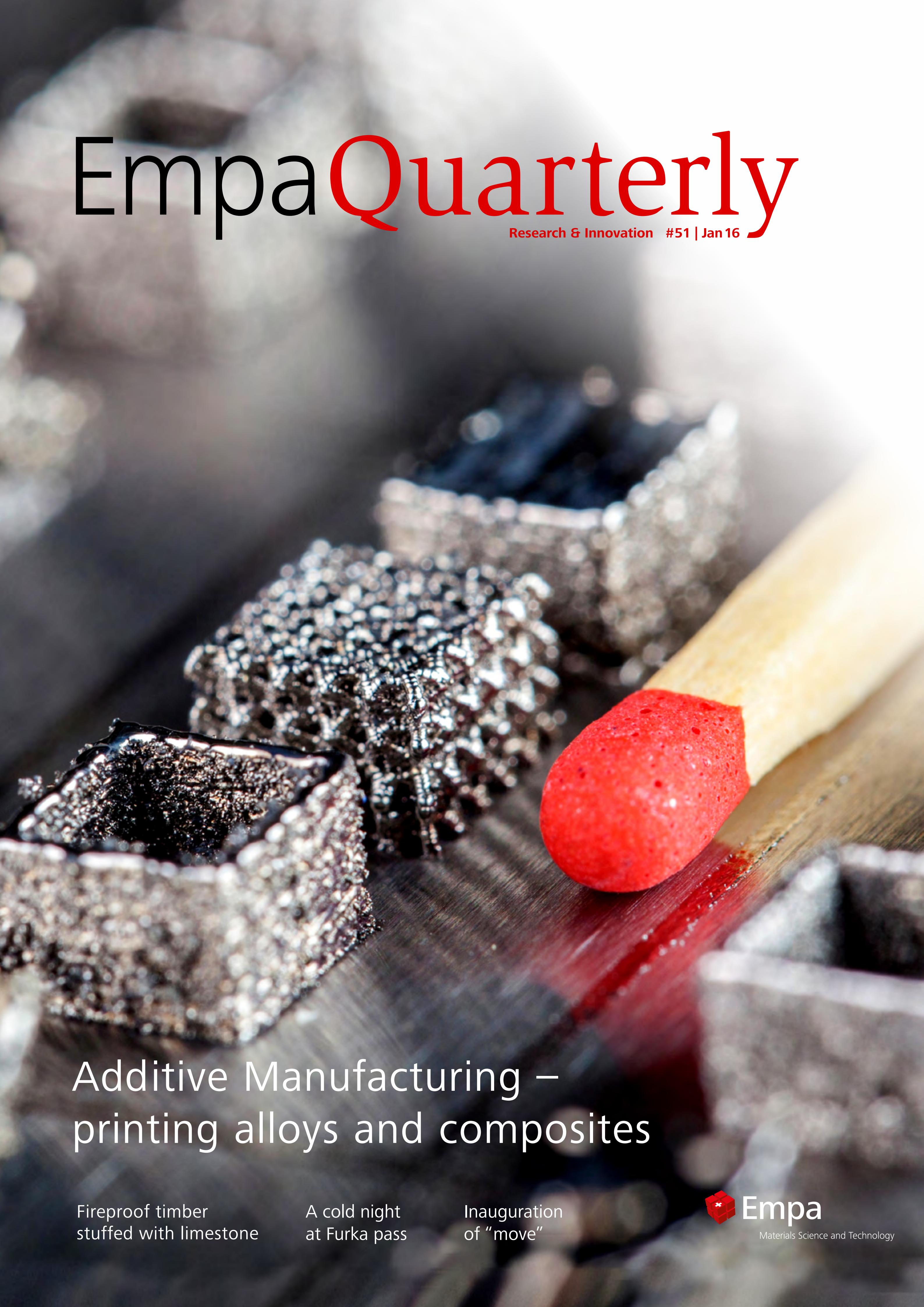


Empa Quarterly

Research & Innovation #51 | Jan 16

Additive Manufacturing – printing alloys and composites

Fireproof timber stuffed with limestone

A cold night at Furka pass

Inauguration of "move"

Empa
Materials Science and Technology

MICHAEL HAGMANN Head of Communications

A facelift (or two) at Empa

Dear readers

Introducing EmpaQuarterly: Our magazine for research and innovation has been given a new name and a slight makeover. After we celebrated the 50th edition of EmpaNews in the last issue, the next chapter begins in a new guise with No. 51. Some things remain unchanged, however: we will still keep you up to date on the latest innovations bubbling away in Empa's cauldron with exciting reports and portraits, informative graphics and spectacular pictures published on a quarterly basis – hence the new name.

Besides the jubilee, however, there were other reasons for our magazine's little facelift. The trusty old Empa logo was recently rendered somewhat more contemporary and elegant, too – see for yourself on the front cover (at the bottom right).

But that's not all: we've also completely revamped the Empa webpage, which has been showing off its completely new look since mid-December. But we didn't focus on aesthetic goals here; instead, the goal was to make it easier for our visitors to access the extremely diverse world of Empa and find their way to the topics they were looking for as swiftly as possible. Whether we have succeeded in this endeavor remains to be seen. At any rate, we look forward to your feedback and comments.

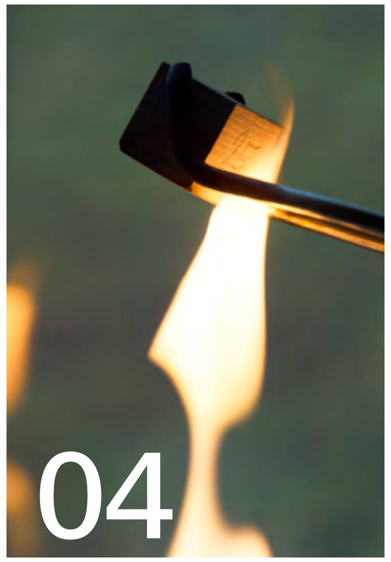
I'd like to draw your attention to our focus topic of the first issue of EmpaQuarterly: additive manufacturing. Many experts are hailing the field as nothing short of the next industrial revolution, with "intelligent" factories and the corresponding production processes and technologies at its heart. Empa scientists and engineers are right in the thick of the action, paving the way scientifically so that Switzerland doesn't miss the boat as an industrial hub.

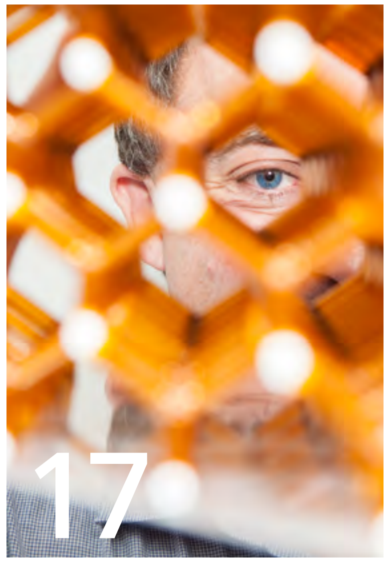
Enjoy reading!

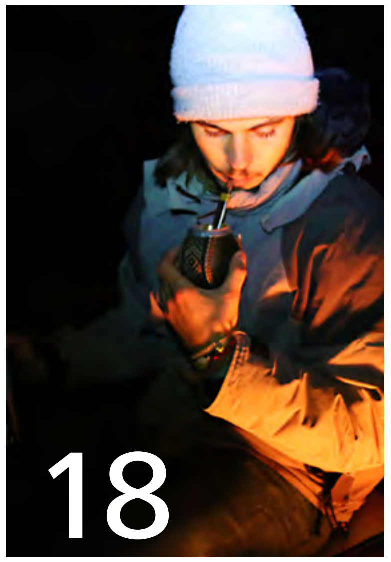
PICTURE: Trumpf GmbH + Co. KG

Focus

Additive Manufacturing







Cover
These tiny sample pieces are made from an extremely light and especially hard titanium aluminum alloy and were produced in a 3D printer. Additive Manufacturing is the technical term used to describe the production of special parts made from metal or ceramic in a laser printer. Empa will play a major role in this development. Image: Empa
Focus on page 8

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Fireproof hybrid wood

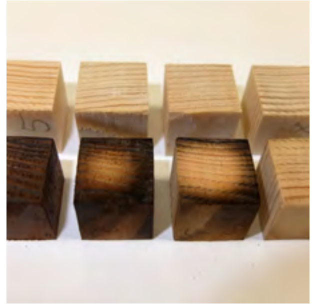
For centuries, wood has been a popular light, solid building material. Moreover, it is a renewable and easily recyclable raw material – with one drawback: wood burns. But this doesn't necessarily have to be that way, as researchers from Empa demonstrate.

TEXT: Lorenz Huber / PICTURES: Empa

Ecological construction is all the rage. Aspects such as the sustainability and energy efficiency of buildings are crucial. Therefore, building contractors and architects are increasingly turning to wood as a construction material because the renewable raw material is both brown and green. Sure enough, wood has many advantages, but also a whole series of challenges. Besides issues of durability and dimensional stability, combustibility is a limiting factor. Until recently, building contractors were not allowed to erect residential and office buildings that were more than six floors high for reasons of fire safety. Even lower structures often required various claddings to guarantee sufficient fire protection. Under the watchful eye of Empa researcher Ingo Burgert, who also runs the Wood Materials Science Group at ETH Zurich, doctoral student Vivian Merk has now discovered a natural way to reduce the combustibility of wood.

Using targeted chemistry to flick the switch

The Empa / ETH Zurich team protects the wood from flames by depositing calcium carbonate (limestone) in the wood's cell structure – mineralizing the wood, in other words. The knack is to get the mineral deep into the structure of the wood. "If I just take the limestone and try to get it into the wood, I don't stand a chance," explains Burgert. "The reaction needs to take place in the wood itself, otherwise it won't work." In order to achieve the desired effect, the researchers soak the wood in an aqueous solution containing carbonic acid dimethyl ester and calcium chloride – a salt that dissolves readily in water, just like the liquid ester. The latter is used as a "green" solvent, for instance. Once the wood has been soaked with the mixture right through to the cells, the researchers increase the pH value by adding caustic soda lye until the solution turns alkaline. "First, we place the substances we need in the wood and then effectively flick the switch," says Merk. Once the mixture has reached a certain pH value, the ester molecules break down into alcohol and CO_2. The latter begins to react with the calcium ions in the solution forming calcium carbonate, which accumulates deep inside the cell structure.



From left to right: wood samples with rising limestone concentrations next to an untreated control sample.

All samples are tested at a defined distance from the flame in flame tests in the lab.

Immersing the sample in the ester solution for several hours ensures that it soaks right through to the cells.

From left to right: untreated wood, treatment with one solution, treatment with two solutions alternately.

Doctoral student Vivian Merk presents the result: the treated wood samples are three times more resistant to fire than untreated wood.

"Vision Wood" in NEST

In parallel to the mineralization work, which has already spawned CTI projects with industrial partners, Ingo Burgert is also conducting other projects that examine the optimization of the renewable raw material from the forest. In his labs at Empa and at ETH Zurich, for instance, researchers are endeavoring to give wood magnetic properties, increase its dimensional stability through polymers in the cell structure or protect the surface of the material from damage by UV radiation. Exactly how the various projects work and can be used in practice will be tested at the demonstration platform NEST on Empa's Dübendorf campus from the spring of 2016. The innovative building concept should help novel technologies to make the leap from research to practice much faster. With this in mind, different, exchangeable building units will be installed, which should enable rapid and applications-oriented research and development for construction materials, housing facilities etc. One of the first housing units will be "Vision Wood". Developed by researchers from Empa's lab for Applied Wood Materials, it focuses on the innovative use of wood as a sustainable resource. As part of the project, mineralized wood should reveal how wood enables ecological housing to be combined with functionality and design.

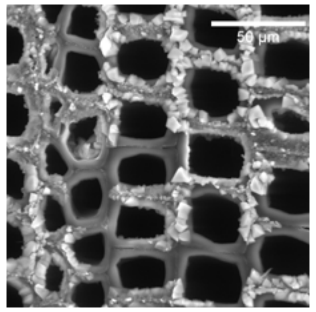
Alternative method in the pipeline

What makes this method so special is the fact that the mineral primarily forms in the cell walls and small pores. In an alternative technique also developed by the researchers, the limestone accumulates directly in the tube-like wood cells and essentially clogs them. The difference with this process is that the researchers work with two different solutions, which they alternate between when soaking the wood. The difference in how the limestone affects the properties of the material when it forms in the cell cavities or in the cell walls is to be investigated in further studies. As far as fire safety is concerned, however, both options work equally well, as Burgert notes: "It's simply a question of embedding as much non-combustible mineral phase in the wood as possible."

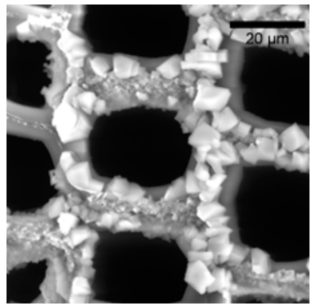
Hybrid material inspired by nature

Ingo Burgert's team takes their inspiration for the development of such organic-inorganic materials from nature. Evolution has yielded a whole series of these so-called hybrid materials: seashells, teeth, mother-of-pearl or bone are just a few examples. Bone is a prime example of what makes a hybrid material so special. The mineralization of its organic structure significantly improves the mechanical properties: In babies, the bones are still soft and only become rigid and sturdy later on.

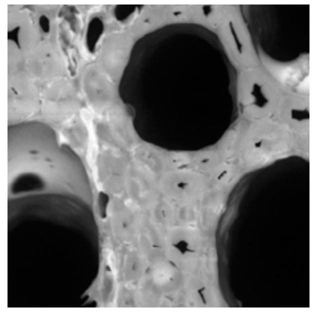
Several fire tests conducted by the group produced promising results. Thanks to the limestone in the cell structure, the researchers were able to reduce the wood's combustibility by about a third. "It works much better than any of us had even hoped," says Merk. The mineralized wood displays many other advantages besides good fire resistance. Both wood and calcium carbonate bind CO_2 inside them, which is very interesting from an environmental perspective. The researchers point out that they did not use any hazardous substances during production or in the end product. Recycling the hybrid wood is thus harmless, unlike normal wood, which is treated with flame-retardant chemicals using conventional methods. "Water-soluble borates are partly used for fire safety, which can have long-term, negative repercussions for our health," says Merk. Moreover, conventional fire protection is often applied to the wood externally. Whereas these surface coatings can come away over time, in hybrid wood the fire protection is embedded deep inside the construction material. //



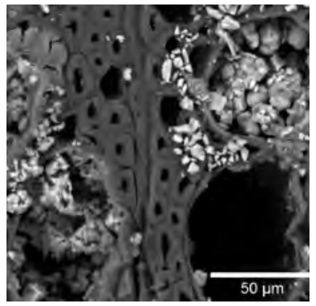
Hybrid wood under the electron microscope: using the production technique with ester and calcium chloride, the limestone crystals are embedded in the cell walls.



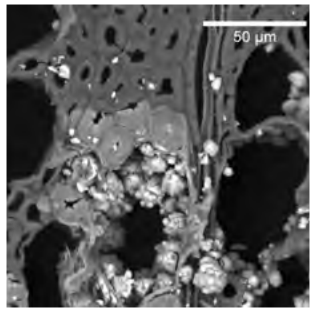
The limestone crystals are clearly visible in the cell walls.



Here's another image of Method 1: limestone in the cell walls.

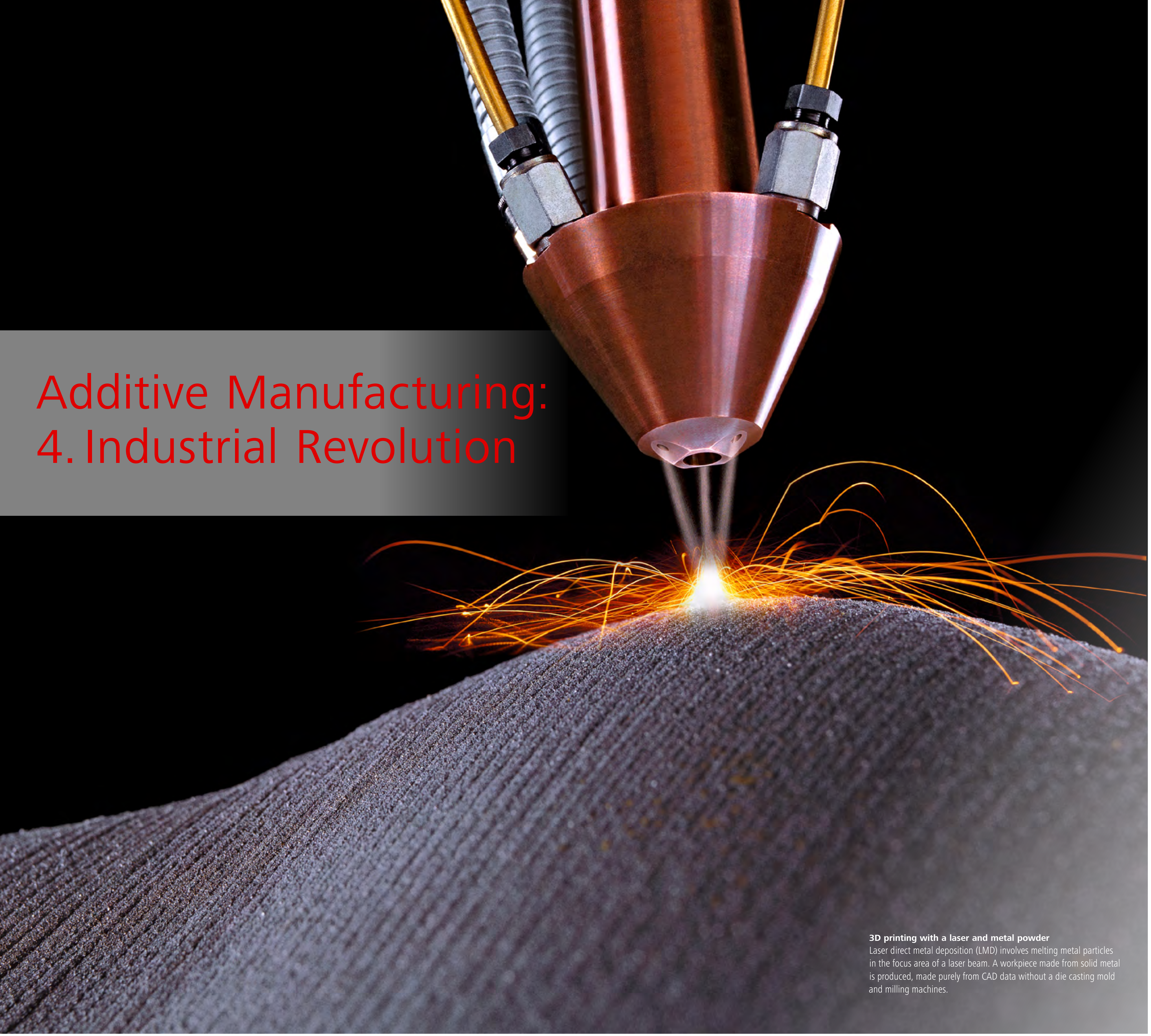


For an alternative technique, which Vivian Merk also developed, two solutions are used alternately.
Here, the limestone crystals are embedded within the cells.



Method 2: limestone crystals are embedded within the cells.

Additive Manufacturing: 4. Industrial Revolution



3D printing with a laser and metal powder
Laser direct metal deposition (LMD) involves melting metal particles in the focus area of a laser beam. A workpiece made from solid metal is produced, made purely from CAD data without a die casting mold and milling machines.

TEXT: Rainer Klose / PICTURE: Trumpf GmbH + Co. KG

The next industrial revolution is imminent. It's called 'Industry 4.0' and is expected to fundamentally change the production methods used in industrialized countries. The leap in development will be similarly dramatic to that experienced in the three industrial revolutions in the past: mechanization with water and steam power in the 19th century – mass production on Henry Ford's production line from 1915 – the use of electronics and IT from the 1970s onwards.

Experts estimate that Industry 4.0 will result in virtual data merging with real production equipment. The resulting "smart factory" will bring customers and suppliers closer together, as production orders will be sent by the customer directly to the machine, and the production data will be transferred to the distribution partner in real time. Manufacturing will become leaner and faster.

Additive Manufacturing – 3D printing in metal

A key component in making Industry 4.0 a reality are machines that can produce the desired components faster, more flexibly and more precisely than ever before. Less prototype construction, fewer dies, less post-processing. In future it will have to be possible to turn data into components and products at an incredible speed.

3D printers give a sneak preview of what this type of production might look like. The first of these devices were created in the 1980s, and nowadays you can buy entry-level devices for less than 700 Swiss francs. But so far, 3D printers have generally been used to make objects from plastic. The mechanical properties and the temperature stability of these objects are pretty limited as a result, which is why they are mainly used for illustrative purposes, i.e. as visual models. This is why 3D printing is often described as "rapid prototyping". For the next industrial revolution, the technique used for 3D printing will have to go one step further: from rapid prototyping to Advanced Manufacturing, the production of lasting and functional components with defined mechanical and thermal properties: products made from metals or ceramics.

Switzerland won't miss the boat

Within the framework of the focus area "Advanced Manufacturing Technologies", the strategic planning of the ETH Board for the ETH Domain for 2017 to 2020 provides for investment totaling 10 million Swiss francs in infrastructure, new academic chairs and technology platforms. The Board has appointed Empa CEO Gian-Luca Bona to coordinate this endeavor. He is tasked to harmonize the interdisciplinary research activities of ETH Zurich, EPF Lausanne, PSI and Empa.

In this issue, we present the challenges that need to be overcome in the development of 3D printing of metal parts – along with the significant opportunities that this technology offers. Empa is working on this topic with different research groups. One group is examining the optimized use of lasers, while another is researching new types of alloys that this technology makes feasible for the first time. A further lab is using Additive Manufacturing to build new, geometric forms that were not possible up to now with the traditional production methods available.

Looking for the magic formula

3D metal printing is simple – or so you might think. But that's not really the case. A lot of details are still complete unknowns. Patrik Hoffmann is tracking down the inside story.

TEXT: Amanda Arroyo / Pictures: Empa

1
A chain made using Additive Manufacturing (AM): the links of the chain are interlinked yet made from one piece. (Design and production: La Manufacture CSC).

Basically, it's just a single, long welding seam." Patrik Hoffmann is talking about Additive Manufacturing, the process by which metal powder is melted with a laser. And when it comes to welding, this researcher knows his stuff. Patrik Hoffmann is head of Empa's Advanced Materials Processing lab in Thun, Switzerland, and has also been teaching "Laser Processing" as a subject at EPFL for almost 20 years now. He and seven of the staff from his lab have set about making Additive Manufacturing more reliable.

"In terms of how lasers and materials impact on each other, no-one knows yet what's really going on", Hoffmann explains. When you look carefully after the workpiece is finished, you can see that material has melted and you can imagine that the original loose powder volume has reduced. But it is not yet quite clear how much of the material vaporizes and spatters off. Hoffmann is convinced that there is a formula for this process. Finding that formula is challenging because the process is highly dynamic and non-linear.

In order to better understand the influence of the process parameters like the laser power, how fast the laser beam moves or the focus diameter, Hoffmann is using a research laser unit designed at Empa. This allows him to use cameras and microphones to track the laser welding process.

Laser processing: an abrupt affair

Laser processing is a tricky and abrupt affair: when someone from Hoffmann's research team focuses the laser with a certain intensity on a gold surface, nothing happens at first. The light is reflected, and just one percent of the radiated energy flows into the material. "If I look in there, I will turn blind before the gold even gets warm", says Hoffmann. When the laser power is gradually increased, a point is reached where the gold gets warm enough to start melting. Melted gold reflects much less light, and suddenly the material absorbs so much energy that part of it vaporizes right away. It's not possible to prevent that from happening. The more gold that vaporizes, however, the denser the steam above the workpiece becomes, until the laser beam can no longer penetrate it. This effect caused by the steam is known as shielding.

Hoffmann and his team use high-speed cameras to measure how the metal steam escapes and where droplets fly to, and they examine the speed of the small shock wave created by the laser. They also monitor the process acoustically, with three microphones attached to the test device, which then record the welding signals. When something goes wrong in welding, you can hear it.

In addition, the Empa scientists also measure the melting pool that the laser creates in the metal. While it's quite easy to visually measure the melting pool diameter, the test device has to be cut open subsequently in order to calculate the depth of the melting pool.

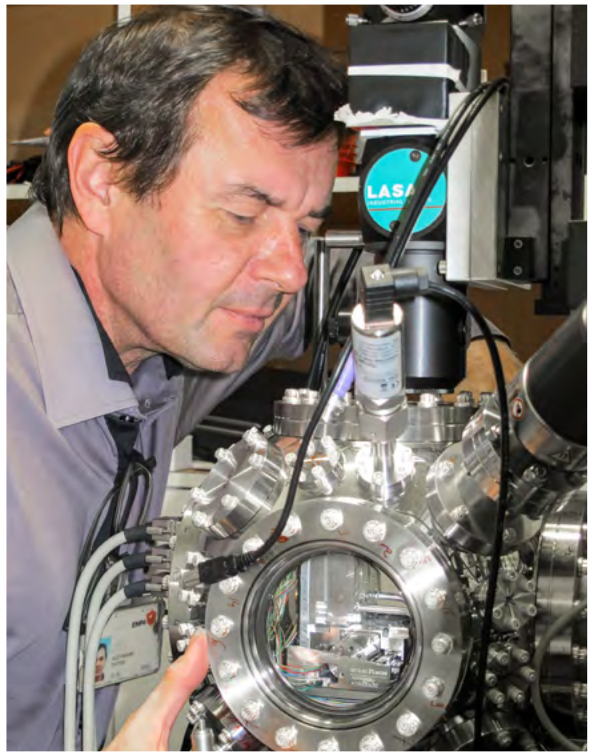
When you look at the cross-section of a test device resulting from Additive Manufacturing, you see not only the horizontal growth of each metal layer deposited, but also vertical crystal growth through the layers. "That's not really surprising to anyone who knows about metallurgy", says Hoffmann. The individual layers are melted up to ten times in this type of production process. This allows crystals to form that spread over several layers. Another challenge is that, because metal is a very good conductor of heat, the melted material cools down very quickly. On the one hand, this property can be exploited to manufacture new materials, for example for powder-enhanced ODS alloys (ODS = oxide dispersion strengthened). On the other hand, the fast cooling rates can also lead to stresses and cracks in the material, rendering the produced workpieces unusable.

His goal: closed-loop process control

To solve this puzzle of understanding the process, the material properties and internal stresses, Hoffmann now intends to involve a range of different experts. To cover all aspects, he will need physicists, solid state chemists, mechanics, acousticians, metallurgists, spectroscopy specialists, electronics technicians and computer simulation experts.

His long-term goal is closed-loop process control, where all of the processes in laser welding or Additive Manufacturing are monitored in real time. If something goes wrong, the control has to automatically correct the laser immediately to make sure that the desired component emerges from the manufacturing process without any internal material flaws, stresses or cracks.

According to Patrik Hoffmann, there are still quite a few ob-stacles for the international research community to overcome before we have a dream factory that is fed with virtual design data and spits out perfectly formed, ready-to-use metal parts. He and his team want to help make the vision of a 3D printing factory ultimately come true. //

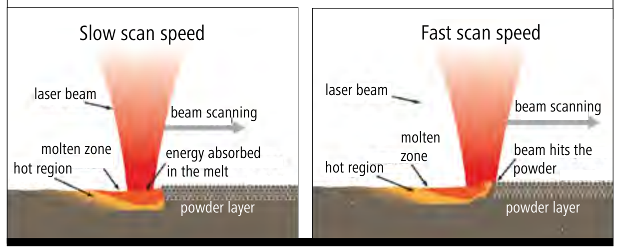


2
Patrik Hoffmann using the Empa-built laser unit: cameras, microphones and mass spectrometers can be connected to the housing of the laser unit. This allows Hoffmann to analyze the mutual interaction between the laser and the metal powder with very high precision.

3
A watch casing produced using AM: the blank is on the left, with a supporting structure beneath the ring that is later broken out. The finished, processed workpiece is on the right. (Design and production: La Manufacture CSC).

What's better: fast or slow?

The trick to Selective Laser Melting (SLM) is to keep production at a slow enough pace. Left: The laser creates a pool of molten metal that solidifies in a controlled manner. Right: The laser hits grains of metal. Some vaporize and some melt partially. This results in pores and inclusions in the workpiece.

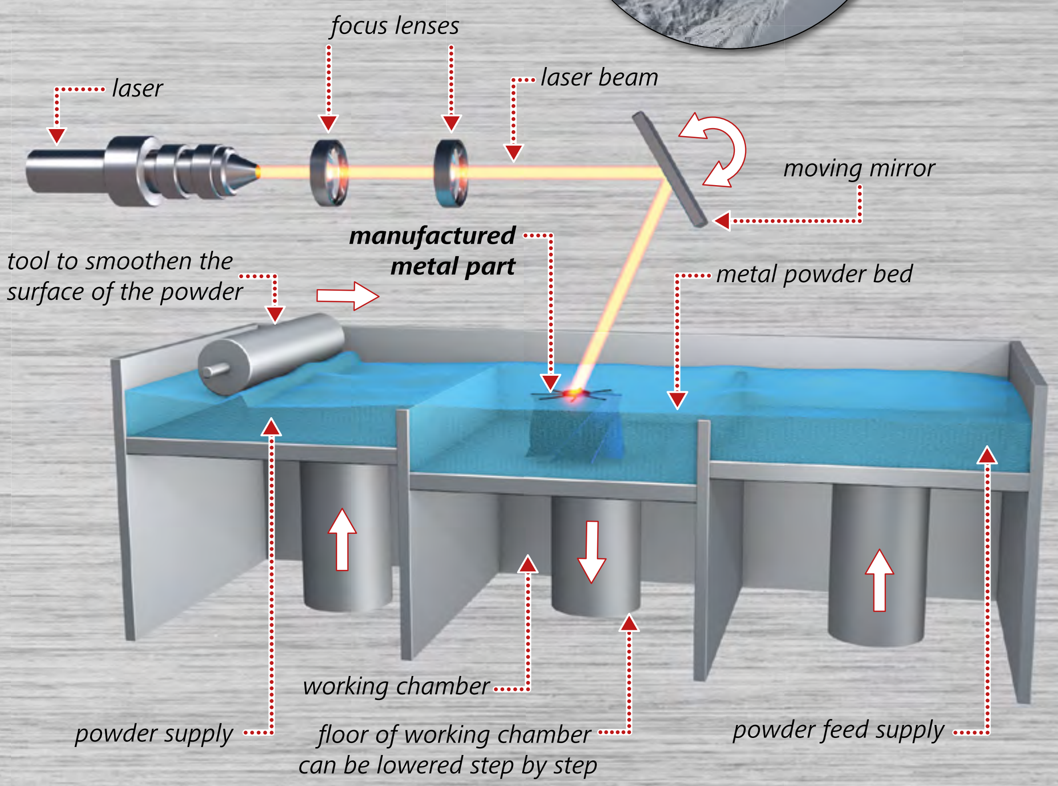


Additive Manufacturing

The first 3D printing processes were developed in the 1980s. Nowadays, 3D printing as part of rapid prototyping is an established technology used to fabricate scale models from plastic very quickly and very flexibly in areas like architecture, engineering or surgery. In future, 3D printing is to be used to produce not only models but real, functioning components with sufficient mechanical properties and adequate heat resistance – as individual pieces and on a small series scale. This is only possible with metals or ceramics. At the moment, there are two methods for forming metallic objects with the help of metal powder and laser beams.

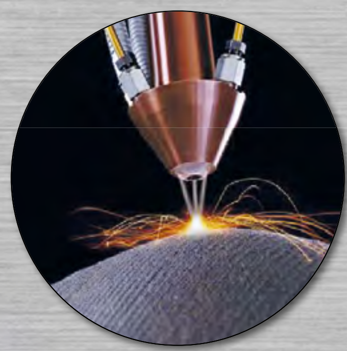
Selective Laser Melting (SLM)

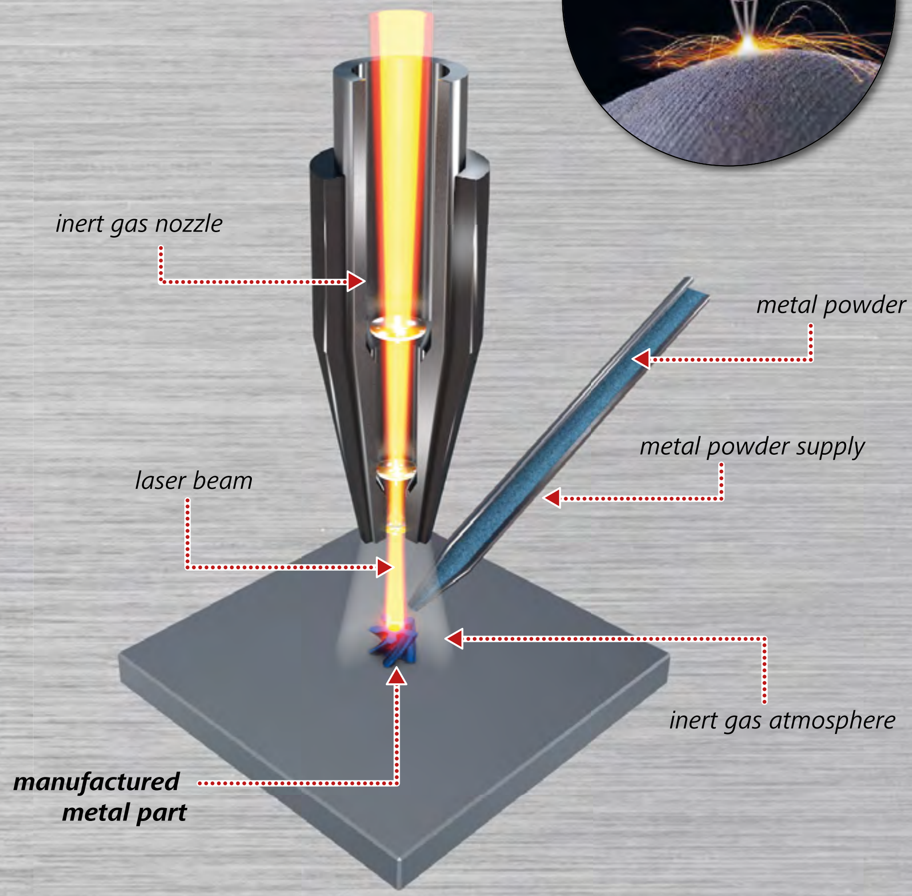
A laser melts powder in a powder bed. After each work step a new layer of powder is added to the resulting workpiece. Then the laser is used again and melts the next layer.



Laser direct Metal Deposition (LMD)

Powder is blown from nozzles into the laser beam and melts at the place where the new layer is required. Up to four different metals can be combined to form an alloy.

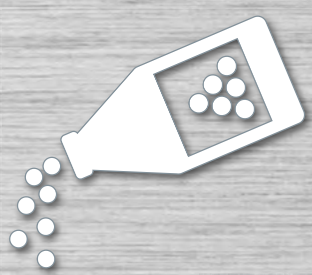




From Lab to Industry

In order to form a completely new industry from 3D laser printing, we need more than just special machines. Lots of things have to be reinvented. New possibilities are opening up in the fields of engineering, high-temperature technology and design as well as in the gearing of companies. Empa is involved in many of the key parts of this process.

Functionalizing powder

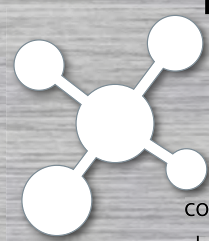


New, pourable metal powder for SLM and LMD *(Empa)*

Optimized laser use

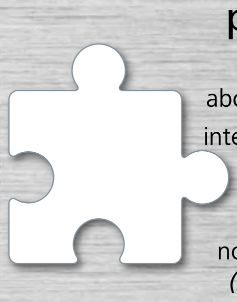
Optimized control of laser beams or electron beams allows for improved material quality and higher production speeds at the same time. *(Empa, EPF Lausanne, Inspire AG)*

Microstructure of the printed component



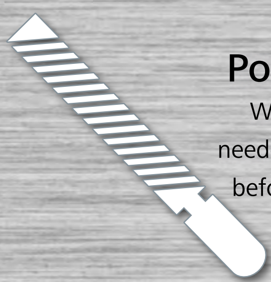
What alloys are created? Can new types of alloys be formed with material gradients? New types of composite materials with a degree of hardness, toughness or temperature resistance never achieved before? *(Empa, EPF Lausanne, PSI, Inspire AG)*

External form of the printed component



What is the surface like? What about trueness to scale? Are there internal stresses in the component – how can they be prevented? Quality control using non-destructive testing methods. *(Empa, ETH Zurich, Inspire AG)*

Post-processing

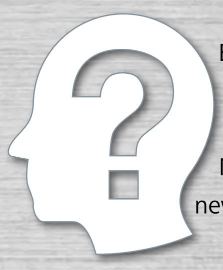


What post-processing is needed for the component before it can be installed? *(EPF Lausanne)*

Recycling

Can the metal granulate from the SLM process be reused? What kind of treatment is necessary? *(Empa)*

Design



Engineers can design components with a geometry that would not be possible in milling processes. New lightweight design concepts, new assembly strategies, new combinations of components become possible. *(ETH Zurich, Inspire AG)*

New 3D printing machines

New concepts for 3D production machines and machine fleets. From laboratory manufacturing to mass production „on demand". *(ETH Zurich, Inspire AG)*

New business models for "Industry 4.0"

Business model for 3D production "on demand". Legal solutions for product liability and certification for individual 3D pieces and small 3D series. *(ETH Zurich)*

Pictures: Trumpf GmbH + Co. KG

Impossible materials get real

There are lots of attempts under way at processing existing metal powder in the best possible way, i.e. adjusting the printing machine to the powder. Empa is going one step further: its researchers are searching for new alloys that are better suited for 3D printing. They are also trying to create new types of composite materials that cannot exist without 3D printing.

TEXT: Rainer Klose / PICTURES: Empa

The last week in November 2015 was a moment that Christian Leinenbach and Christoph Kenel had been waiting for for a long time: the 3D printing machine "M2 cusing" is installed and connected up in the new lab on the Empa campus. This means that from 2016 onwards it will be possible to carry out trials with different metal alloys, laser speeds and line distances. The machine by the German manufacturer Concept Laser can use a fiber laser to create complex 3D components made from metal with dimensions of up to 25 cm each. "However, most of our test devices are much smaller", says Christian Leinenbach. "On the one hand we want to develop new materials adapted to the manufacturing process, and on the other we want to research how we can use Additive Manufacturing to create completely new materials."

Searching off the beaten path

Research into 3D printing with metal is booming, with conferences on the topic taking place constantly all over the globe. Leinenbach has been following the articles published on the scene and has discovered a certain imbalance. Out of over 200 contributions presented at various international conferences over the past two years, an astonishing 75% deals with just three different classes of materials: the famous titanium alloy Ti-6Al-4V, commercially available nickel-chromium alloys and stainless steel. "It is easy to see why so much research is being carried out into precisely these alloys", Leinenbach tells us. "They are of huge commercial interest for aviation and aerospace, for the defense industry and offshore construction. In contrast, little or no research has been carried out into many of the materials that are of interest for Swiss industry, such as tool steels or precious metals." A fundamental understanding of the mutual interaction between the material and the laser is also often forgotten about. As a metal specialist, Leinenbach is critical of this approach: "With a complex system of three or more metals and numerous phases, it's very hard to develop functioning components on the basis of trial and error. There are just too many variables."

Basic research with titanium aluminides

Together with his doctoral student Christoph Kenel, Leinenbach has, therefore, focused his attention on alloys made from titanium and aluminum as part of an EU project. The low density of these materials makes them interesting for parts in aircraft engines for example, but they are very difficult to process. These two metals alone develop more than a dozen different phases with different mixing ratios and temperatures, and only one mix of two phases is suitable for technical use. This phase system has long since been carefully researched, and it's precisely in this well-researched field that it's worthwhile uncovering new processing methods with the help of AM.

The two researchers already started with their first experiments long before the laser unit was installed at Empa. One experiment examined the influence of the cooling rate of the bath on phase formation. While classic methods like molding with maximum cooling rates of several tens of degrees per second are well understood, there has been a virtual lack of research to date into the events that take place during laser melting. Cooling rates of more than 10,000 degrees per second are possible in the very small melting pool created by the laser. This means that suddenly phases stabilize at room temperature that do not usually occur at that temperature at all. Leinenbach and Kenel experimented on titanium aluminide with a special test set-up in different compositions with cooling rates of up to 15,000 degrees per second. They compared the results with simulated calculations. In this way, they more or less created a map of an area of metallurgy that was largely uncharted. With these findings, the Empa researchers were able to identify a new alloy that is significantly better suited to processing in a 3D laser printer than the titanium aluminide materials currently available.

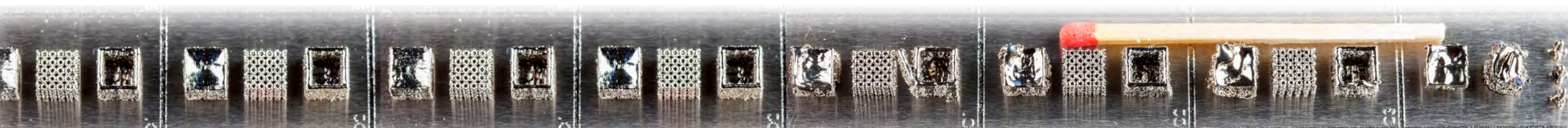
Sample pieces made from titanium aluminide with embedded ceramic particles. Because of its low density, this alloy is of interest for aircraft a engines for example, but it is difficult to process. The sample pieces show which parameters are best for 3D printing.

Left side: Christian Leinenbach at the newly installed 3D laser printer.

Dream materials for grinding machines

One initial tangible result of the high cooling rates in the 3D printer could be new types of composite materials made from metal and diamonds. Sintered diamond tools with a simple geometry are already used to grind ceramic components. But it is very difficult to produce metal-diamond composites using conventional melting methods. If you put diamonds in contact with fluid metals, they generally dissolve or swim to the surface due to their low density. Also, diamonds are made from pure carbon, and they melt at air temperatures above 400 degrees. Together with partners from ETH Zurich and inspire, Leinenbach and Kenel succeeded in producing metal-diamond composites in the 3D printer. They did this by mixing small industrial diamonds with a powder made from a copper, tin and titanium alloy. The diamonds remained intact after the process and are also coated with a thin titanium carbide layer that puts them firmly in the metal matrix from a chemistry perspective. In future it should thus be possible to produce tools with a more complex geometry than those that exist today.

Here too though, it's fair to say that the alloys we know today are definitely not best suited for processing with 3D printers. Further developments will follow. So the newly installed 3D printing unit on the Empa campus will soon be running round the clock. //



Pierangelo Gröning is a member of Empa's General Management. He coordinates research into AdditiveManufacturing. In the EmpaQuarterly, he explains where the journey is taking us.

INTERVIEW: Rainer Klose / PICTURES: Empa

"We want to provide know-how for machines of the future"

Mr. Gröning, what role does Empa play in Additive Manufacturing (AM)?

The ETH Board has named Advanced Manufacturing as a strategic research focus area for the period from 2017 to 2020. The method of 3D printing using metals is just one of various different elements of Advanced Manufacturing, which in general involves new and more modern production techniques. These new techniques are of major importance to Switzerland as an industrial location. We have to be strong in this area in order to hold our own in the face of international competition going forward.

What different areas, materials and AM methods is Empa focusing on?

As a materials research institute, we see the major challenges for 3D printing in the processing of metals and ceramics. The methods we are looking into include Selective Laser Melting (SLM), Laser direct Metal Deposition (LDM) and Selective Laser Sintering (SLS).

Is Empa also going to offer courses to teach skilled specialists about Additive Manufacturing?

Empa is a research institute first and foremost. We firstly want to understand all the laser processing methods thoroughly. Subsequently we will develop new raw materials that will be optimized for 3D printing. The aim of the research is to take 3D printing of metals from where it is today in terms of manufacturing and transform it into a robust and reliable industrial method. We are not going to get involved in the actual process engineering, i.e. operating lines or designing and optimizing the printing process for components. We feel that Switzerland's universities of applied sciences and institutes like the ETH spin-off inspire would be better suited to that task. The same applies with regard to training skilled specialists.

Nevertheless you have just commissioned a 3D laser printer at Empa. What are you going to do with it?

We do of course need machines for our research that we can use to process the newly developed materials in real-life conditions and with the best process monitoring possible. One of those machines is a commercial 3D printer that has been modified to incorporate sophisticated process monitoring functions. But we will also set up our own research equipment and use it to examine very closely the mutual interaction between the laser and the materials as the creation process of the workpiece and thus also of the material and to one day control that process.

So the aim is to control the process in real time?

Exactly. We want to provide know-how for machines of the future that can control the laser processing process.

What changes can industrial firms expect when they start using Additive Manufacturing?

One of the consequences is that quality management has to be completely reorganized. Today, we produce a number of parts in series construction using traditional process engineering. We remove samples, test them and use the findings to draw conclusions about the quality of the manufacturing process. With Additive Manufacturing, we will be creating individual parts or small series, so it will no longer be possible to work with samples. This means that we will have to monitor the whole production process, from the provision of the powder to the completion of the workpiece. Because you can't use destructive testing if you only have one part. The manufacturer will have to provide the complete production logs to the customer that buys the individual part, as that's the only way to guarantee the quality of the product. As researchers, it is our job to provide the basics for this new type of production. We have to learn to understand fundamentally how such a workpiece is created by the laser beam, what errors take place and how to recognize and avoid these errors.

A magic crystal kills vibrations

Soaking up vibrations with the help of crystal structures? It sounds a little esoteric, but it's not. Two Empa researchers have shown that it is possible. The 3D printer helped to build the test models.

TEXT: Rainer Klose / PICTURES: Empa

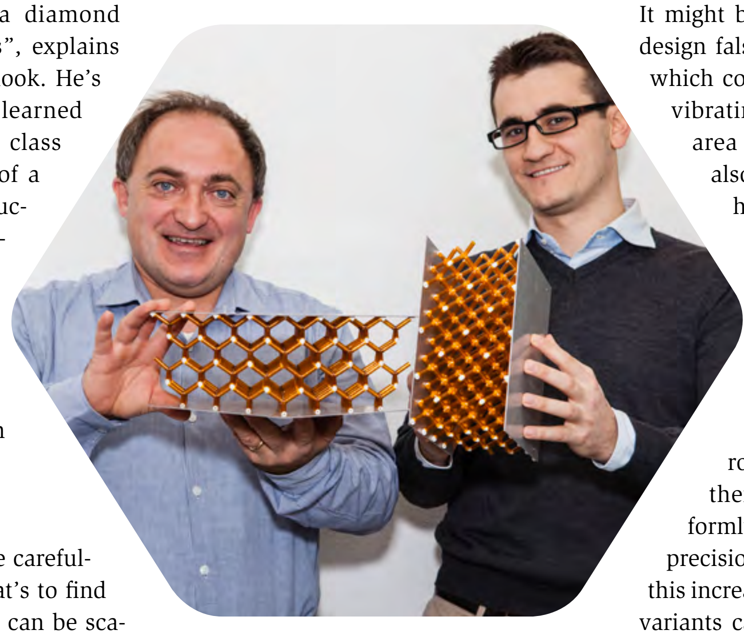
What do you see there?", asks a smiling Andrea Bergamini. In his hands he is holding a sandwich design made from two thin aluminum sheets. In between there is a grid structure made from orange-colored pipes and white connecting pieces. It looks like a carefully executed and very tidy DIY project that doesn't have any purpose. "There's a diamond structure between these sheets", explains Bergamini, and I take a closer look. He's right: anyone who has ever learned about diamonds in chemistry class and looked at a crystal model of a diamond can recognize the structure. The white connecting pieces in the model are tetrahedrons, just like the carbon atoms in a diamond. But what's it all about? What's the point of a model of a diamond in between two aluminum sheets?

On the trail of Paul Scherrer

There's a daring idea behind the carefully prepared DIY project, and that's to find out if the properties of a crystal can be scaled up several notches and made usable. Exactly 100 years ago, the Swiss physicist Paul Scherrer together with his Dutch colleague Peter Debye developed the Debye-Scherrer method, which is still in use today. The method makes it possible to determine the structure of crystalline substances by means of X-ray diffraction. But X-rays are nothing more than electromagnetic waves that are diffracted by the crystalline structures. Some of the waves cancel each other out, while others amplify, creating the characteristic blot pattern around the crystal. The incident X-rays waves are broken up into small bundles of waves and thrown back in different directions.

The secret life of macrocrystals

If you now magnify the crystal structure millions of times, could this structure break up and diffract bigger waves? Like sound waves or vibrations? That's the question that Andrea Bergamini and his colleague Tommaso Delpero set out to answer. They built the sandwich model from aluminum sheets and parts of a molecule-building kit. For comparison, they made a second model with just hard foam between the aluminum sheets. Together with their colleagues from Empa's Acoustics / Noise Control lab, Armin Zemp and Stephan Schönwald, they then secured the two models in a vibrating device and watched what happened. And hey presto! As expected, the foam swallowed up the vibrations uniformly, while the crystal structure developed a life of its own. Some of the vibrations were practically reflected back, with the aluminum sheet that was being shaken moving faster, while the underside of the sandwich structure was not vibrating at all. The researchers had discovered what is known as a "band gap" in the macrocrystal – a property that also plays a central role in semiconductor technology. Within this band gap, the macrocrystal does not transmit any vibrations.



Andrea Bergamini and Tommaso Delpero

Precise models from the 3D printer

It might be possible to use this finding to design false ceilings that absorb vibrations, which could be used as a base to support vibrating machines. Other uses in the area of mechanical engineering are also feasible. But now the researchers have to move beyond their DIY model with all of its typical flaws. To do this, they can use the metal 3D printer now available at Empa. The device can convert geometrical data from theoretical calculations directly into a crystal structure. The macrocrystalline intermediate layer is then printed permanently and uniformly from metal, eliminating the imprecisions of the DIY project. Thanks to this increased precision, different structural variants can be easily compared. Research into the vibration-swallowing crystal will take off as a result. //

Publication: Delpero T., Schoenwald S., Zemp A. and Bergamini A. (2015). Structural engineering of three-dimensional phononic crystals. Journal of Sound and Vibration, 1–10. doi: 10.1016/j.jsv.2015.10.033

A night beneath the stars

The start-up Polarmond has developed an innovative sleeping system in collaboration with Empa researchers. The bivouac is expected to revolutionize comfort while sleeping outdoors in temperatures as low as minus 30 degrees Celsius. EmpaQuarterly reporter Lorenz Huber decided to find out whether the product delivers what it promises. So he packed his rucksack – and spent a night on the Furka Pass.

TEXT: Lorenz Huber / PICTURES: Lorenz Huber, Empa

The first snowfields loom in front of me on the north face of the Furka Pass at an altitude of around 2,000 meters. This November, the snow has only stuck wherever the sun doesn't show its face all day long. On top of the pass, there's a plateau so I stop my rental Toyota to take in the view. As soon as I open the car door, however, a surprisingly strong gust of wind slams it shut again. I brace myself for the second attempt. On the short walk to the edge of the plain, I have to hunch up my shoulders and hold my hand in front of my face. The wind peppers my skin with small hailstones, which sting like whiplashes. The temperature is just below zero – conditions that shouldn't be a problem for the bivouac I plan to sleep in. The start-up Polarmond teamed up with researchers from Empa to develop this all-in-one sleeping system for temperatures as low as 30 degrees Celsius. It shouldn't get below 25 degrees beneath the liner in the spacious interior. The product passed the lab test in Empa's climate chamber; now it has to prove itself in practice.

From the top of the pass, the view stretches across to the Uri face of the Urserental. In the other direction, you gaze down on the Valais municipality of Obergoms. A few lone, determined sunrays pierce the dark clouds in the sky and illuminate the snow-covered mountaintops. The pass road, which snakes its way up both sides of the slope, isn't exactly busy. I drive on for another few meters, come to a fork in the road, veer to the right up the slope and park outside a small wooden hut.

With the bivouac tightly packed and lashed to the rucksack, I begin the climb. A trail leads past the hut, which I follow for a while, keeping my eyes peeled for a spot to set up camp for the night. The wind makes a constant, temperamental companion, intermittently blasting its tempestuous gusts, which tear up anything that isn't firmly rooted to the ground. On two occasions, I only just manage to hold onto my woolly hat. I eventually find a suitable spot; a flat area, roughly five by ten meters in size. A boulder offers a little shelter from the wind. As it's already getting dark, I immediately start pitching the tent. Due to the treacherous weather, my efforts to lay out the bivouac parts aren't particularly successful. The sleeping system comprises the following components: a blue sleeping shell with a high-performance insulating layer; two frames, which provide shape and stability; a sleeping mat, which can be incorporated into the sleeping shell; an orange weather guard, which can be attached to the sleeping shell thanks to a clever zip system; and a liner, which conducts away the moisture from the sleeper's body.

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The bivouac is fairly foolproof. The sleeping shell has an opening at the top, where you push – or rather squeeze in – the sleeping mat, but this is the only somewhat more arduous task. The frame, on the other hand, is a piece of cake to assemble: at the top and bottom of the sleeping shell, there is a loop on both sides, through which you thread the ends of the tent poles and attach them at the bottom. Black hooks fastened to the outside of the sleeping shell conveniently click into the frame. In order to protect your face from the elements, you now affix the weather guard, which is also quite easy. Two zips and a Velcro fastener provide a water-proof seal. Finally, you secure the bivouac to the ground with a total of five lines.

The job described here, which would be a pushover in normal weather conditions, is at least twice as difficult in heavy, irregular gusts of wind. Any pieces that you aren't holding need to be weighed down with stones. Once I finally get the sleeping mat in the shell and start sticking the individual parts of the frame into each other, the wind hits me at full force again and sends everything flying. The two stone weights are powerless against such a strong gust and the sleeping shell takes off along with the sleeping mat. It's literally catapulted about 15 meters up into the air and shoots off towards the valley, upon which I let out a loud curse and sprint frantically after it. Fortunately, I reach the tent before the next gust of wind. The subsoil poses the next challenge. A few centimeters beneath the greenery, I hit rock, which makes it difficult to plunge in the tent pegs attached. After bellowing another string of expletives and enlisting the aid of some rocks and the heel of a shoe, I eventually manage to secure the bivouac.

Dusk has already fallen and there's barely a car on the road. Right next to the rock, someone has piled up stones into a low wall to make what looks like a makeshift pen that measures around three square meters in size. Against all the odds, I manage to get a fire going inside this corral. Although my elation is short-lived – the little wood I found by the roadside on the way up is rotten and burns reluctantly and briefly – it still gives off a little heat. As the last beams of sunlight sink behind the mountains across the valley, I settle down next to the fire and brew up a mate tea. This traditional Argentinian drink, which you sip from a hollowed- and dried-out pumpkin through a metal straw with a filter, always makes a sterling traveling companion. As the wood hasn't exactly left any burning embers behind, I have to resort to a camping stove to prepare my supper: tinned lentils with bacon.

When darkness finally falls, I sit down so that I can see the bivouac in the beam from my headlamp. At first, I'm dubious about the reliability of the tent pegs. But regular checks to the lines set my mind at ease. Although the bivouac takes quite a pounding from the wind, it stands firm. I can see the odd star between the clouds. The temperature has dropped way below freezing and all that remains of the campfire is a dull glow. It seems like midnight. In reality, however, it's just after six. The lentils go down a treat.

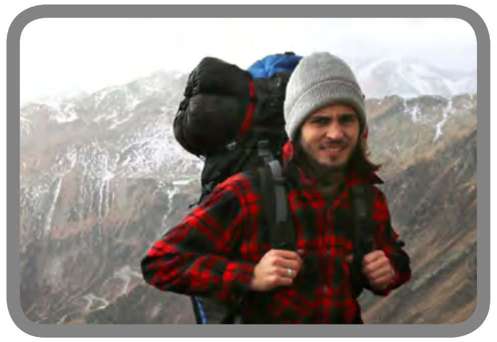
When my feet start to feel like blocks of ice, I decide to turn in for the night. Eager to find out whether the product actually lives up to its promise, I crawl into the bivouac. Getting in is easier said than done – although, to be fair, I do make a meal of it. It takes me a while to position myself correctly in the liner and wriggle my feet into the foot section. I wait impatiently for the insulation to work its magic. And sure enough, after a few minutes the interior starts to warm up. Still in my winter coat at first, I gradually peel off my clothes until I'm lying there in just my underwear. There's plenty of room in the bivouac. Spread out next to me in the shell are: a camera, complete with its case; my winter jacket, trousers, shirt and hiking boots. Even though it's almost as comfy as lying in a bed, I have trouble getting off to sleep. The mountain wind is still thrashing the bivouac mercilessly, which makes an infernal din inside. I'm a bit worried about my rucksack, which had to stay outside. Although I can feel the gusts of wind a little inside, before long it's so warm that I have to unzip the temperature control.

The next thing I know, it's half past midnight. There's no sign of the wind anymore and the night is deathly still. The temperature in the sleeping shell is still pleasant. I decide to go outside to check the stability of the tent and the whereabouts of my rucksack. When I glance up, the beauty of the view almost takes my breath away. There isn't a cloud in the sky and I have an obstructed view of the starry night – a sea of sparkling little particles, framed by the dark, jagged silhouettes of the mountains.

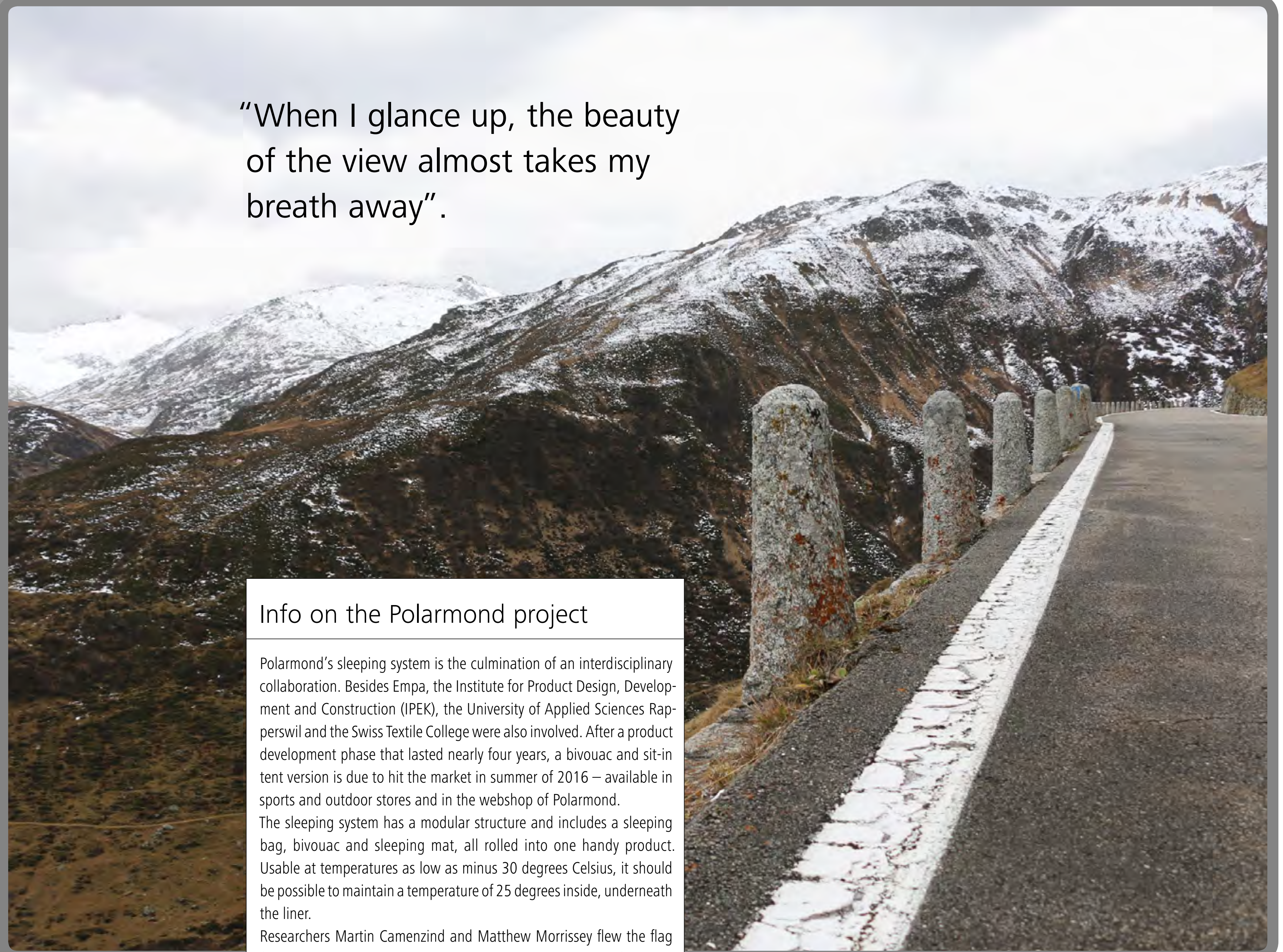
The rucksack is fine and the bivouac is still firmly anchored to the spot. When I lie back down, I leave the weather guard open so I can up gaze at the stars. Suddenly, something stirs in the heavens: a shooting star streaks across the sky, the first of many. The large, rapid ones leave glowing trails in their wake, which burn in the night sky – and my retina – for a few moments. I just lie there for about three quarters of an hour, my body in the warm sleeping shell, my face exposed to the icy mountain air. This time, I have no trouble dropping off.

At seven o'clock, it's time to get up. After ten hours in the bivouac, the temperature inside has dropped somewhat. But that's hardly surprising seeing as the ventilation slit remained open all night long. The inside of the weather guard is blanketed in hoarfrost. As I clamber out, I brush against the orange-colored material and get a wet head. The fact that my body is already warm, however, makes the transition into the cold morning air perfectly bearable. The ground, my rucksack and the bivouac are covered in morning frost. The wind is still calm, which makes dismantling and tidying up the campsite a cakewalk compared to last night.

After collecting all my belongings I entered my car and drove down to Zurich quite relaxed. It had been quite a comfortable night in the mountains. The Polarmond bivouac surely passed the test. //



Reporter Lorenz Huber climbing up to the campsite, his bivouac and rucksack on his back. Winter nights start early in the mountains: lights on in the tent from 8 p.m. The Polarmond bivouac the next morning before being packed up: weather guard, liner, camping mat and sleeping shell in separate pieces, ready to be put away.



"When I glance up, the beauty of the view almost takes my breath away".

Info on the Polarmond project

Polarmond's sleeping system is the culmination of an interdisciplinary collaboration. Besides Empa, the Institute for Product Design, Development and Construction (IPEK), the University of Applied Sciences Rapperswil and the Swiss Textile College were also involved. After a product development phase that lasted nearly four years, a bivouac and sit-in tent version is due to hit the market in summer of 2016 – available in sports and outdoor stores and in the webshop of Polarmond.
The sleeping system has a modular structure and includes a sleeping bag, bivouac and sleeping mat, all rolled into one handy product. Usable at temperatures as low as minus 30 degrees Celsius, it should be possible to maintain a temperature of 25 degrees inside, underneath the liner.
Researchers Martin Camenzind and Matthew Morrissey flew the flag for Empa during the project, helping to solve the problem of thermal insulation and dehumidification.

Further info at www.mikeott.ch/wordpress

In November there is little traffic out and about on the Furka Pass. Our roving reporter spent the night near the pass road to test out the tent.

Empa on the front cover

Empa concrete specialists Beat Münch and Andreas Leemann made it onto the front cover of the Journal of Microscopy with their publication. They developed a new concept for the identification of minerals based on images. The pictures are taken in an electron microscope using energy-dispersive X-ray spectroscopy (EDS). The electron beam scans the surface of the sample. As every chemical element gives off a characteristic X-ray pattern, a separate image is produced for every component. Using an automatic, two-step technique, Münch and Leemann managed to combine these individual images to produce an overall image, which is able to separate and identify the distribution of the materials reliably, and is considerably more informative than individual images of element distributions.

http://onlinelibrary.wiley.com/doi/10.1111/jmi.12309/full

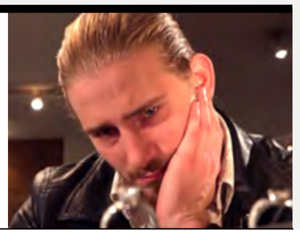
A touch of Hollywood

Congratulations to Lorenz Huber, a former intern in Empa's Communications section! His short film Kairos beat 84 competitors in the Eastern Switzerland Short Film Competition to finish third in the Over-20s category.

Empa's espresso machine can be seen in a supporting role – and the office where this magazine is made. The budding filmmaker also set off into the mountains as one of our roving reporters. Read his feature on pages 18–20 of this issue.

Preisgekrönter Kurzfillm «Kairos»

https://youtu.be/Chyt9IOB70U



ClimeWorks clinches Swiss Excellence Award

The Zurich-based start-up ClimeWorks won the Swiss Excellence Award for an outstanding product innovation on October 26, 2015. ClimeWorks produces the CO_2 collector – a machine that works autonomously and, thanks to technology developed at Empa and ETH Zurich, extracts 135 kilograms of carbon dioxide a day from the ambient air. It enables businesses to produce the carbon dioxide they need themselves, completely independently of suppliers and infrastructure. And for higher demands, several CO_2 collectors can be combined into a large system. Six collectors can be stacked in one 40-foot container.

www.climeworks.com

Federal Councilor Doris Leuthard visits Empa's mobility demonstrator

Top energy and mobility experts attended the inauguration of the research and technology transfer platform "move" on Empa's Dübendorf campus on November 23, 2015. Thanks to this facility, Empa researchers will spend the next few years studying how surplus renewable energy can be converted into fuel for cars, utility vehicles and machinery and thus be used as energy. The name "move" doesn't just stand for motorized mobility, but also the switch from fossil to renewable energy – all the way to the realization of a closed carbon cycle modeled on nature.

Doris Leuthard, Head of the Federal Department of the Environment, Transport, Energy and Communications (DETEC), had already visited Empa for a meeting two weeks earlier. She used the occasion as a welcome opportunity for an exclusive tour of the brand new research platform. Brigitte Buchmann, a member of Empa's Board of Directors, and Christian Bach, Head of Empa's Automotive Powertrain Technologies lab, explained how "move" works to the Federal Councilor.

Events (in German)

13. Januar 2016
FSRM-Kurs: Versagen von Hightech-Komponenten
Zielpublikum: Industrie und Wirtschaft
www.empa.ch/verskomp
Empa, Dübendorf

14. Januar 2016
FSRM-Kurs: Klebetechnik für Praktiker
Zielpublikum: Industrie und Wirtschaft
www.empa.ch/klebetechnik
Empa, Dübendorf

26. Januar 2016
Brennstoffzellen in automobilen Anwendungen
Zielpublikum: Fahrzeug- und Energiefachleute
www.empa.ch/fcv2016
Empa, Dübendorf

01. März 2016
FSRM-Kurs: Graphen und Kohlenstoff-Nanoröhrchen
Zielpublikum: Industrie und Wirtschaft
www.empa.ch/graphen
Empa, Dübendorf

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

Your way to Empa´s knowhow:

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www.empa.ch/portal

Well, there is one more thing…

… and that is our new webpage – completely overhauled, with new functionalities and a brand-new design. It will give an overview about Empa's R&D activities, showcase our events, videos, news and much more. On your desktop, your laptop, your tablet or your smartphone.

Have a look for yourself on www.empa.ch