"Our job is to supply information **for a more sustainable future."**

Christian Große develops new technologies for non-destructive testing, and employs a wide range of methods to discover hidden damage. The ultimate aim is to improve the quality and safety of structures, industrial production processes and many everyday objects, and to determine what causes deterioration

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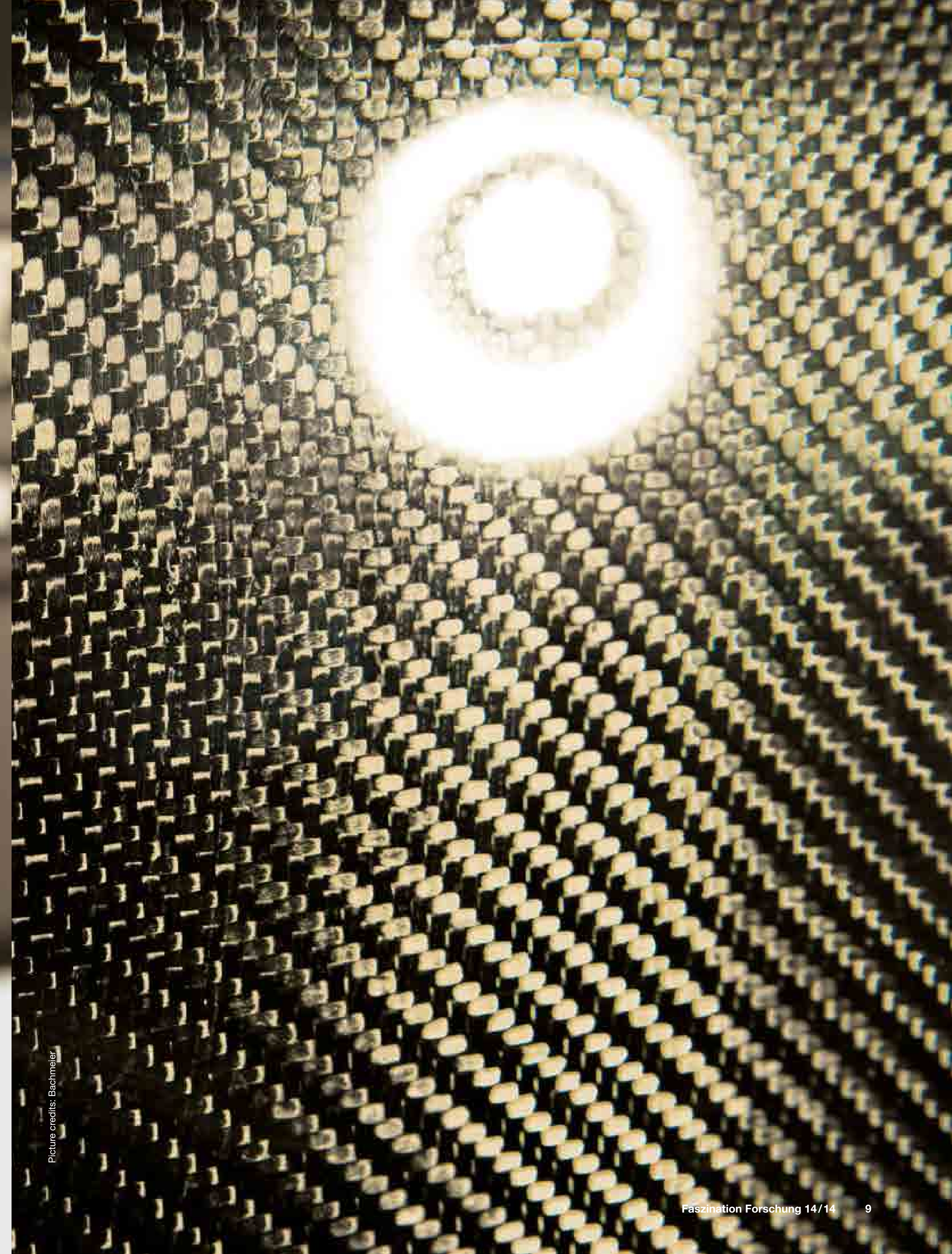


Carbon fiber reinforced polymers under scrutiny: Material defects show up under a light source using infrared thermography

Picture credits: Bachmeier

Ultrasound inspection of a car front hood made of carbon fiber reinforced polymers along marked measurement lines

Picture credit: Bachmeier

„Wir liefern die Information für Nachhaltigkeit"

Verborgene Schäden in Materialien, Bauteilen und Konstruktionen zu erkennen – das sind Ziele von Prof. Christian Große und seinem Team vom Lehrstuhl für Zerstörungsfreie Prüfung (ZfP). Mithilfe der verschiedensten Verfahren schauen die Wissenschaftler in Objekte hinein und ermitteln die physikalischen oder chemischen Eigenschaften. Heute ist ohne zerstörungsfreie Prüftechniken keine Gas- oder Ölversorgung, kein Start eines Flugzeugs, keine Herstellung eines Autos oder eines Zuges und kein Bau sicherheitsrelevanter Bauwerke wie Brücken, Tunnel, Hochhäuser und Fahrbahnen denkbar. „Als Informationslieferanten tragen wir dazu bei, Werkstoffe nachhaltig zu verwenden und damit die Umwelt, die wir Menschen gestalten, zu schützen", bringt es Große auf den Punkt. Denn auf der Grundlage der Messungen lassen sich Qualität und Sicherheit von Bauteilen und Bauwerken erhöhen, aber auch die Kosten-, Zeit- und Energieeffizienz von Produktionsprozessen positiv beeinflussen. Ein Beispiel ist die Aushärtung der Harzmatrix bei Faser-Werkstoff-Verbundmaterialien: Lässt sich dank zerstörungsfreier Prüftechnik der richtige Aushärtezeitpunkt bestimmen, kann der nächste Gussprozess schneller eingeleitet werden.

Eine Querschnittswissenschaft, die nachhaltig wirkt

Von großer Bedeutung ist die Zerstörungsfreie Prüfung zudem bei Objekten unseres kulturellen Erbes, beispielsweise um Aufschluss über den Schädigungsgrad von Kunstgegenständen zu geben. Die Beispiele zeigen: Das Arbeitsgebiet der Zerstörungsfreien Prüfung erfordert Kompetenzen in vielen Schlüsseldisziplinen wie den Materialwissenschaften, der Messtechnik und der Datenverarbeitung – und es ist höchst abwechslungsreich. So kommt es vor, dass Große morgens im Museum arbeitet, mittags eine Brücke begutachtet und nachmittags bei einem Automobilunternehmen eine Arbeitssitzung hat. Die TUM hat dieser Vielfalt Rechnung getragen und den Lehrstuhl als Joint Appointment in den Fakultäten Bauwesen und Maschinenbau angelegt. *Gitta Rohling*

The world premiere of the BMW i3 was staged simultaneously in New York, London and Beijing. And it was more than its electric motor that created quite a stir. Equally impressive is the fact that the new vehicle is made of carbon fiber reinforced polymers (CFRP). Its launch therefore marks the start of a transition from metal to composite materials in the automobile industry. One of the advantages of CFRP is that, unlike metal panels, no cracks, bumps or dents show up on the surface. While this is undoubtedly a good thing in terms of esthetics, there is a downside: just because you can't see the damage doesn't mean it's not there. Invisible flaws could even compromise the vehicle's reliability.

This is where Professor Christian Große and his team from the Chair of Non-destructive Testing come in. They are able to identify and assess hidden defects in all kinds of materials, components and structures – including CFRP components.

The use of CFRP for the bodywork of series-produced vehicles may be new in the automotive industry, but the aircraft industry has been using CFRP for some time now. Not all CFRPs are the same, however, and testing methods cannot be simply transferred from one industry to another. That is why industry and research players teamed up for a three-year project dedicated to the development of methods for testing fiber composites for the automotive ▷

Did the front hood suffer from an incident? Non-destructive testing of the hood of a roadster would show material defects, since defects change the thermal flow in the material. This can be observed in the infrared spectrum

Picture credits: Bachmeier

Using all sensors and senses to assess the innermost structure of an object without destroying it: Professor Christian Große develops testing technologies to investigate new materials such as fiber reinforced polymers for aircrafts. The scientist is equally fascinated by the capability of humans for non-destructive testing: "Visually examining an object, tapping on a piece of pottery or running a fingertip over a surface – these methods have been optimized by evolution and used throughout the ages"

Inspecting the composite structure of an aircraft tail unit using infrared lock-in thermography

Picture credit: Bachmeier / Graphics: ediundsepp

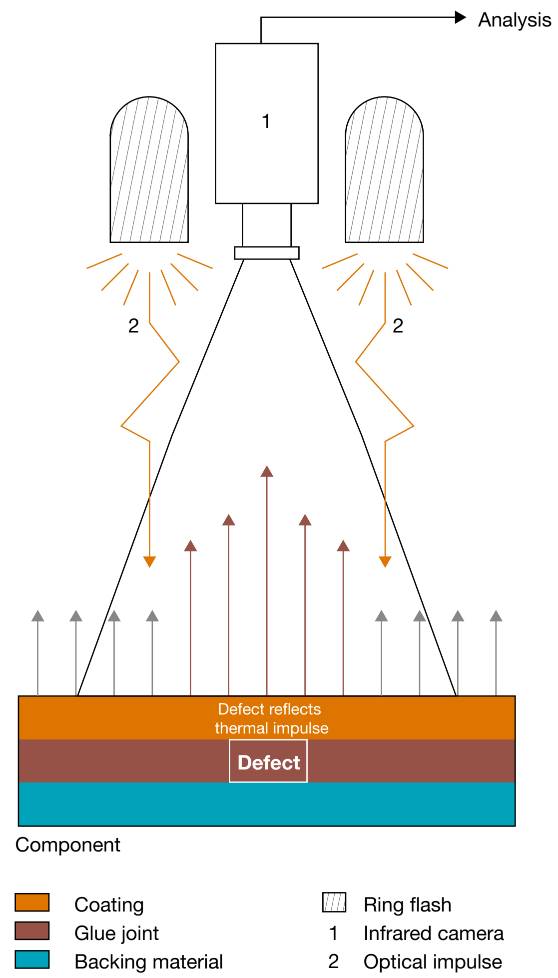
and aeronautical industry. "Which was a challenge not to be underestimated," stresses Große. There are in fact several hundred potential testing procedures. Many are derived from medical technology – such as microscopy, radiography and ultrasound – or from geophysics, which includes geoelectrics, magnetics and seismology. "For this project, we are using computer tomography (CT) reference measurements," says Große. CFRP components that were, for instance, exposed to impacts are put into a computer tomograph. The computer then evaluates the X-ray images from the CT, exposing invisible damage. The project partners are now comparing the findings of the various different testing methods with the CT scans. "CT can tell us a lot, but it is not a universal solution. Besides, it is very expensive, so is not likely to become a standard testing procedure for high-volume production in the automotive industry," adds Große. What the project partners are actually aiming for is the integration of cost-efficient non-destructive testing (NDT) into the manufacturing process. This includes automatic data-processing techniques or so-called big data solutions for a huge amount of NDT data.

From works of art to rotor blades to bridges – it can be measured

Developing suitable test methods for CFRP is just one of the areas that the Chair of Non-destructive Testing specializes in at TUM. "We cover a very broad range of activities," declares Große. An important means of quality control and assurance, non-destructive testing is used for applications as diverse as assessing automobile components during manufacture, identifying damage in rotor blades for a wind farm, or predicting the lifespan of safety-critical structures like bridges, tunnels, high-rise buildings and rail tracks. NDT also plays an important role in preserving our cultural heritage, for instance by shedding light on the level of degradation suffered by works of art. Biomedical engineering is another area where NDT experts can make a useful contribution. Große and his team are cooperating with doctors from Klinikum rechts der Isar, TUM's university hospital, to analyze how a human femur fractures. Their aim is to discover whether the fracture starts inside the bone and spreads outwards, or whether microfractures in the cortical bone are responsible for the break. If a conclusive answer is found, doctors will be able to develop improved prophylactic and treatment therapies for patients who suffer chronic pain, osteoarthritis and restricted movement following such a fracture.

An interdisciplinary field full of fascination and future potential

As the examples above show, non-destructive testing requires competence in multiple key disciplines, including materials science, measurement technology and data processing. It is also applied in incredibly diverse fields. A typical day for Große can involve working in the museum in the morning, examining a bridge at lunchtime and visiting a car manufacturer in the afternoon. To reflect this diversity, TUM has made the chair a joint appointment between the Department of Civil, Geo and Environmental Engineering and the Department of Mechanical Engineering. Große himself is a geophysicist by training who started out by studying the Earth – "in a non-destructive way, of course," he smiles. After obtaining his doctorate and lecturer qualification, he conducted research into structural health monitoring at the prestigious University of California in Berkeley. He was appointed Associate Director and later Provisional Director of the Materials Testing Institute of the University of Stuttgart, and in 2010 he was appointed to the newly created Chair of Non-destructive Testing at TUM. "I was always interested in different fields of research," he explains. That is why he takes his inspiration from his- ▷



Defects inside carbon fiber reinforced polymers show up under a strong light source using infrared lock-in thermography. The light as an electromagnetic wave heats the material up and defects act as hot or cold spots, which alter the thermal flow in the material. Changes in this flow can easily be detected in the infrared spectrum using IR cameras

torical figures like Galileo Galilei and Leonardo da Vinci. “Both men had access to limited information and hardly any opportunity to exchange ideas with other scientists. On top of that, they had to contend with religious and moral constraints. Yet despite all this, both men made some highly important discoveries,” continues Große.
So what exactly does he find so fascinating about his current field of research? “The idea that human beings themselves are excellent non-destructive test systems.” Große smiles, then elaborates: “The human race developed a very good sensory system as we evolved – our sensory organs are wonderfully adept at carrying out NDT.” Visually examining an object, tapping on a piece of pottery or running a fingertip over a surface – these are non-destructive testing methods that have been used throughout the ages. For centuries, these simple tests were the only way to inspect components up to the point of failure or even destruction. However, when the Industrial Revolution took off around the middle of the 19th century, demand for raw materials increased sharply. So industry was suddenly faced with the need to conserve resources and at the same time guarantee workers’ safety. This prompted the intensive development of methods to test a material without destroying it.
Nowadays, non-destructive testing techniques are indispensable in many sectors of industry. Without them there would be no gas or oil pipeline systems, planes could not take off, cars and trains could not be manufactured and safety-critical structures like bridges, tunnels, high-rise buildings and train tracks could not be built. “Our job is to supply information for a more sustainable future – by helping to protect the environment that we are all shaping,” summarizes Große. The measurements he takes can help to improve the quality and safety of components and structures as well as the cost, time and energy efficiency of production processes. These are aspects of considerable importance to Germany as an industrial location in its bid to fend off competition from low-wage countries. One example of where NDT comes in useful is in curing the resin matrix for fiber reinforced composites: if the right curing time can be determined through non-destructive testing, the subsequent molding process can be started sooner.

Non-destructive Testing (NDT)

Non-destructive testing (NDT) uses measurement technologies and data analysis methods to investigate the physical or chemical properties of objects and inspect them for damage without needing to destroy them. The most commonly used techniques include ultrasound, radar, microwaves, infrared thermography, vibration and acoustic emission testing and radiography as well as visual techniques like microscopy. This type of testing is used to support quality assurance, inspections and continuous monitoring.

Quality assurance: Nowadays, non-destructive testing is included in most manufacturing processes to reduce the rate of defects and optimize process efficiency.

Inspection: NDT methods can be used to inspect objects for damage on a once-off or occasional basis.

Continuous monitoring: Cracking processes that occur in microseconds can be monitored just as easily as damage to a bridge that happened over a period of years. The intervals between each measurement depend on the test object and range from seconds/minutes to hours/days.

NDT is an interdisciplinary field and – as a methodology – is not restricted to any particular material or application. It is a branch of materials testing and is mostly used for applications in civil or mechanical engineering.

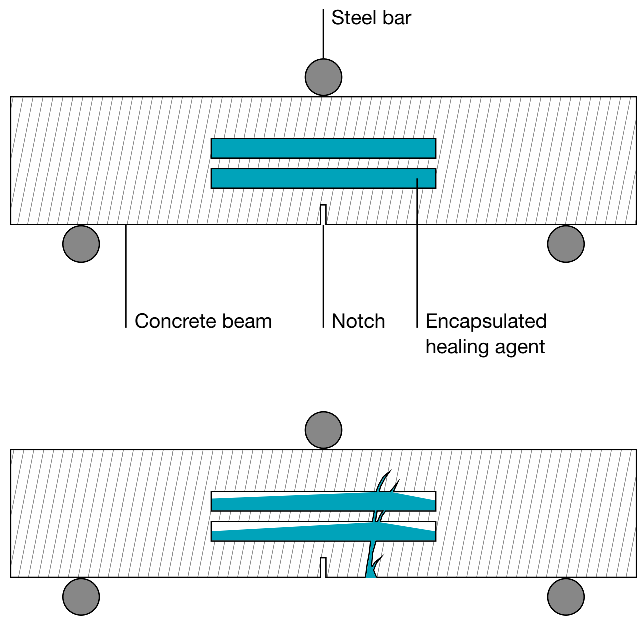
What seems like science fiction is actually science fact

Große has an impressive example of the capabilities of NDT revolving around concrete – one of the most important materials of our time. Over 10 billion tons of concrete are produced annually across the world. This volume is enough to build 100,000 ten-story office buildings complete with underground car parks – assuming that each building would require 10,000 tons of concrete. “The quality assurance of concrete is still very much in its infancy, however,” maintains Große. He and his team are developing state-of-the-art ultrasound techniques to determine the properties of a concrete mix. “Our ultimate aim is to give every new building or structure a “birth certificate” documenting all of its properties. This should subsequently facilitate the job of maintenance,” he declares.
Cracks in a concrete structure could result in water or salt ingression. These can result in corrosion processes that attack the steel reinforcement and thus cause significant damage to the structure. Identifying the cause of deterioration requires experience – and intuition. Große reveals more by turning to another important project, focusing on concrete that is able to “heal” itself. He is investigating three self-healing mechanisms that were developed by colleagues from the Universities of Ghent and Delft. One of these involves bacteria that live within the concrete. These are dormant most of the time, but when they come in contact with water that has seeped into a crack, they “produce” calcium carbonate, which helps repair the cracks. Although this sounds like science fiction, it actually seems to work. The second approach uses hydrogels, which elsewhere are used in diapers to absorb moisture. The idea is that the hydrogel will swell on contact with water, thus filling the cracks. The third mechanism is based on tiny capsules filled with polymer-based resin which is released when cracks cause the encapsulation to break.
Self-healing concrete is of particular interest for structures that frequently come into contact with salt – such as highway bridges and buildings located by the sea. “Our job is to observe how cracks occur and how the healing ▷

Inspection of the wing of an aircraft made of a mix of glass and carbon fiber reinforced polymers. Measurements with ultrasound phased-array sensors help in determining material structure

Picture credit: Bachmeier

Left: Three-point bending test of concrete with self-healing capabilities. A technician prepares ultrasound sensors and sticks them onto a concrete beam containing capsules with a healing agent. The capsules break under pressure. Ultrasound and acoustic emission measurements show whether the agents are activated and all voids are properly sealed



Self-healing concrete: Capsules containing a healing agent (blue) are incorporated inside a concrete beam. They break under pressure and the agents are activated releasing the resins into the cracks and seal them

agents are released. Then we assess how efficiently the healing agents did their job," says Große. He and his team have developed or refined many procedures with this in mind – from acoustic emission analysis for lab studies to wireless sensor nodes for non-stop monitoring. Initially, the mechanisms are tested on small objects before moving on to full-scale components. In the third phase, Große and his team perform their measurements on real structures. For this purpose the procedures have to be completely robust and practicable. Although self-healing concrete will be more costly, it has advantages that could compensate for this. For example, it can potentially increase the lifetime of a structure and reduce maintenance intervals. In addition, thanks to its special properties, it may save raw materials at the construction stage.

Whether it is concrete, CFRP or some other material, Große knows that he will be kept busy: "Safety and quality requirements are becoming stricter and stricter, and new testing methods need to be developed all the time. We have our work cut out for us." *Gitta Rohling*

Picture credits: Bachmeier/Graphics: ediundsepp