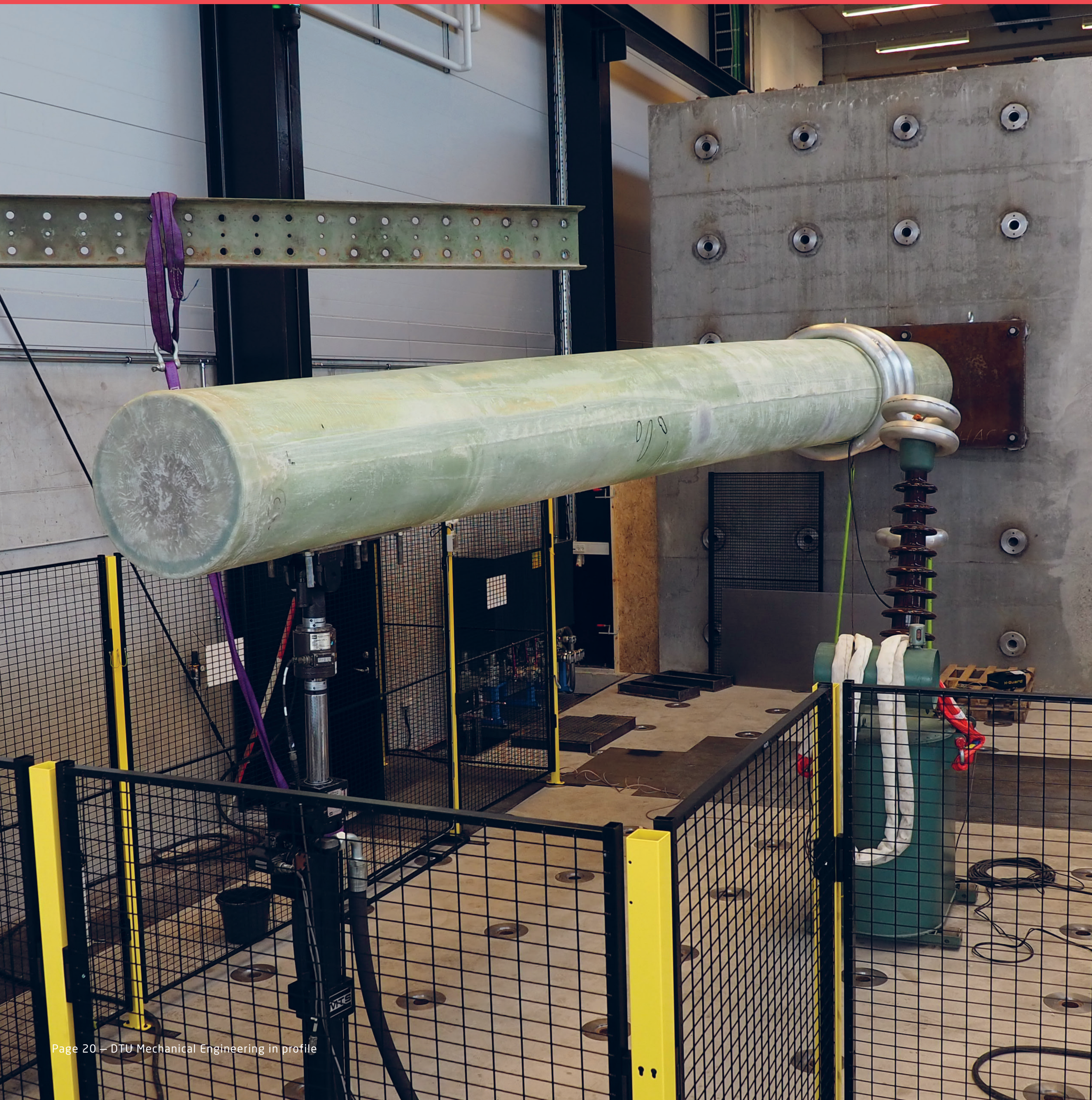
Materials and constructions of the future

New knowledge on materials is essential to optimise and tailor them for specific applications and improve the many products that surround us in everyday life.



Part of the research at DTU Mechanical Engineering focuses on materials, including their related manufacturing processes and their performance in constructions and products. The work includes basic research on understanding, describing and developing materials, as well as more application-oriented research, which departs from meeting performance challenges. The challenges can relate to many different performance parameters, but typically focus on combinations of strength, fracture, toughness, corrosion and wear of materials.

"The continuously increasing size of wind turbines is a good example of this. The enormous forces that wind gusts impose on the gears and bearings in the drivetrain can be detrimental and lead to premature failure. As researchers, we can contribute to solving this problem by examining where and how the materials fail, in order to provide options for material optimisation. In other words, we take the challenge into the laboratory, where we look into the material and try to find out why the damage occurs and how it can be avoided. For example by proposing another material or a specific treatment that leads to improved performance," says Professor Marcel Somers.

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3D printing could kick start a renaissance

Marcel Somers' research team also works with material technologies in relation to 3D printing, which can significantly change the use of a material. Titanium is a splendid example of this. The application of titanium has previously been very costly due to the manufacturing, which includes both its synthesis and shaping by conventional cutting and deformation processes.

"Titanium is an interesting material because it combines high strength with low weight and is abundant in the earth's crust. With the help of 3D printing, it could experience a renaissance and become relevant for many more applications than is the case today. Titanium is therefore a material that we are intensively researching into," says Marcel Somers.

Surface microstructure of selective laser melted titanium (3D print), showing the result of an island scan strategy with different patterns in the islands. Each island has dimensions 0.5 x 0.5 mm. Image taken with digital reflected light microscopy.

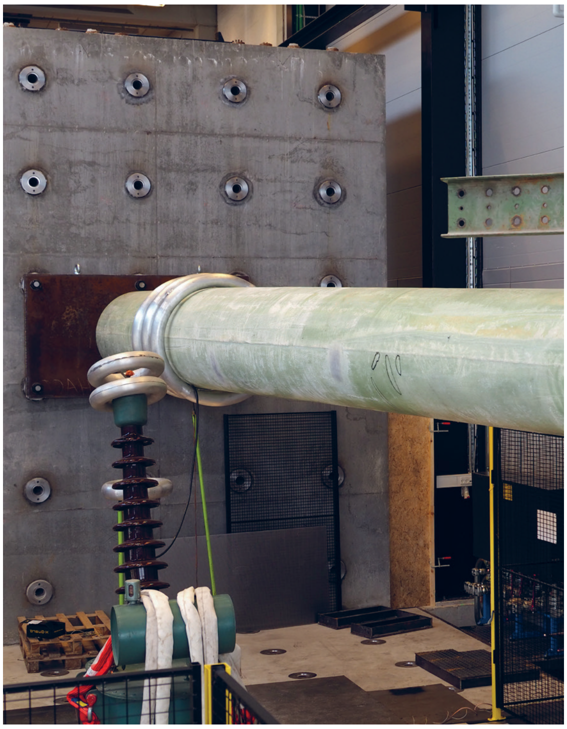
The properties of a 3D printed metal are not the same as those of the metal we otherwise know. In the 3D printing process, metal powder is melted together layer-by-layer. The repeated heat impact and subsequent rapid cooling means that the 3D printed titanium must have post heat-treatment to ensure the same strength as conventional titanium. Furthermore, a surface treatment is necessary to improve the wear resistance of titanium to widen the application potential.

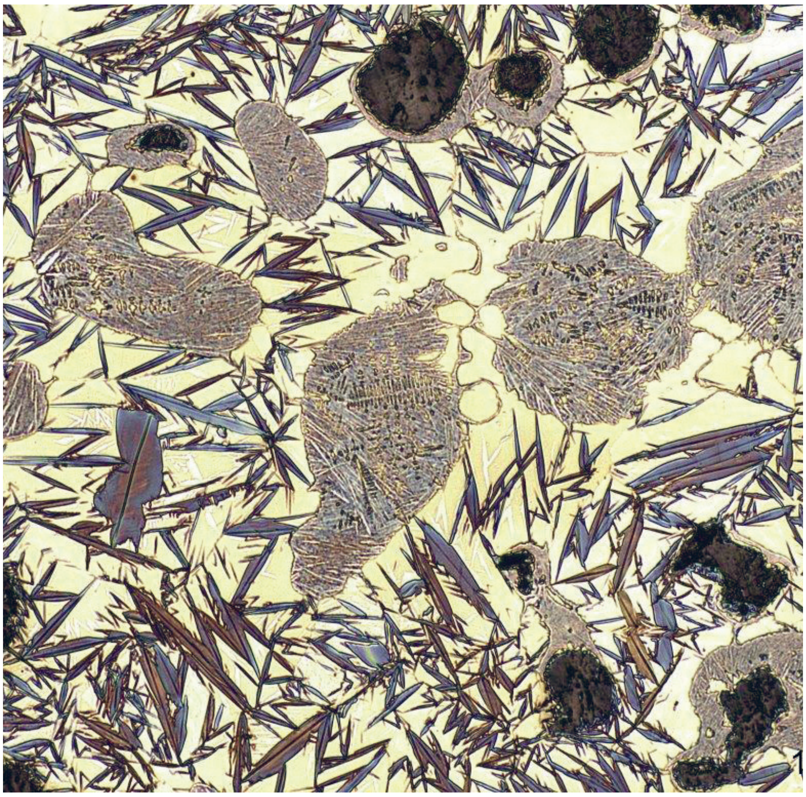
New technology gives researchers new opportunities

New methods and technologies also make it possible for researchers to challenge and improve the knowledge gained over the years on different types of metals and their properties.

"Today, we have powerful electron microscopes, which makes it possible to study the microstructures of the metals in two dimensions in high resolution and in much detail. With the help of x-ray and neutron technologies, we can now also look into the material and characterise the microstructures in 3D and see what happens when the metal is used. This provides great insight into how the metal reacts when it is exposed to e.g. stress or heat," explains Professor Dorte Juul Jensen, who is leading an ERC (European Research Council) Advanced Grant project.

With this new insight in 3D, it has proved necessary to revise many of the previous theories on the behaviour of metals.





Microstructure in over-heated and partly melted ductile cast iron, showing solidified regions with dendrites, spheroidal graphite (black), lenticular martensite (leaflets) and retained austenite (yellow). Image taken with reflected light microscopy.

"Whereas we have previously based the analysis mainly on mean values, we now have the opportunity to look into the metal at the crystal level and see its internal structures and strains and thus the local variations in 3D. This gives us new knowledge to understand for example the properties of the metals. In the long run, this new knowledge will help reduce the very large safety margins that many engineers have worked with in their constructions and thus contribute to resource savings, says Dorte Juul Jensen.

The new insight into the properties of metals is not only generated with the use of advanced characterisation techniques, it is also related to new possibilities for handling big data. Machine Learning may be used to assist the researchers in revealing trends in the measured data caused by inhomogeneity in the material, and which the researchers have not identified on the basis of the usual analysis methods.

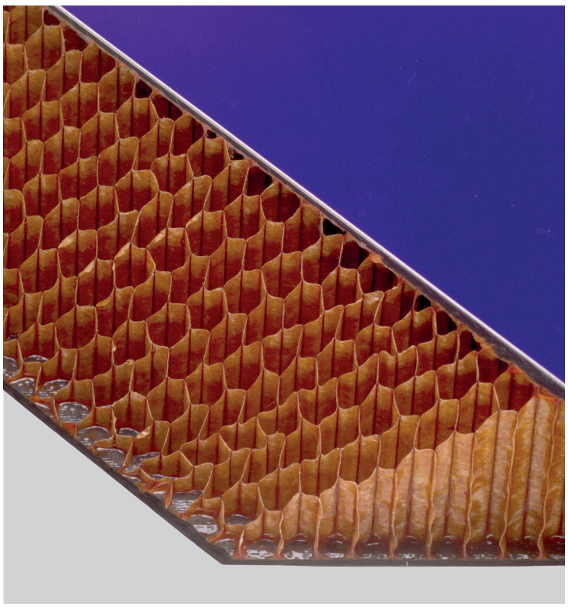
"This is important, as even small metal improvements can be of great importance and lead to much better properties, saving raw material and increasing safety due to lower risk of fracture, for example," emphasises Dorte Juul Jensen.

Composite materials for means of transport

So-called 'composite materials' is another group of materials that the researchers at DTU Mechanical Engineering conduct extensive research into. These are very light materials that are typically used in

transportation means such as aircraft, ships and land vehicles, as well as in other weight-critical constructions as wind turbine blades, where both strength and stiffness are essential.

"Our research focuses among other things, on the so-called 'sandwich materials'. A light core material of, for example, structural foams or honeycomb structures is placed between two thin layers of fibre composites, to give the desired strength and stiffness



necessary in a component of a ship hull, the tailplane of an aircraft, the blade of a wind turbine or in the underbody of a car. And it does so without considerably increasing the total weight of the construction," says Associate Professor Christian Berggreen, who heads the research on lightweight constructions at DTU Mechanical Engineering.

Research in this area focuses on the damages that can occur in composite materials and components, and on the speed with which the size of cracks increase during use. The goal is to provide users of the construction with the knowledge to assess whether a damage is harmless or in need of repair.

"Part of our work is to develop simulation models based on laboratory testing of the materials and components from which the constructions consist. During testing, the materials and components are exposed to real-life conditions such as low temperatures or large pressure differences encountered by ships and aircrafts, respectively. The simulation models are subsequently used as supportive decision tools when deciding if a particular damage requires repair," says Christian Berggreen.

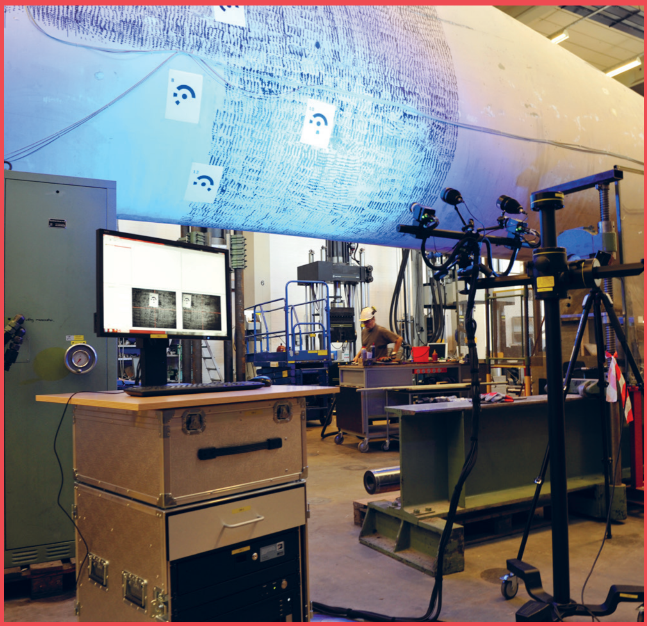
The researchers at DTU Mechanical Engineering are at the forefront, internationally, within lightweight constructions, collaborating with e.g. NASA, Airbus and the US Navy on advanced sandwich materials for aircraft and ships. Other partners include the Danish Defence, which needs lightweight vehicles for international missions that are both easy to transport and strong enough to withstand roadside bombs, for example.

Composite materials are used in weight-critical constructions as e.g. wind turbine blades where both strength and stiffness are essential.

World-class research facilities

DTU hosts world-class facilities for the analysis and testing of materials and constructions. Several advanced microscopes, both electron and x-ray microscopes, can be found in the university's laboratories, where the microstructures and internal stresses of the materials can be studied.

In addition, the university has established a multi-scale testing facility, CASMaT, Villum Center for Advanced Structural and Material Testing, where large constructions of composite, concrete and metallic materials can be tested in newly established and advanced facilities. Part of CASMaT consists of the laboratory unit DTU Structural Lab, which is used both for teaching and research in the field of mechanical testing of materials and constructions in addition to offering test services to companies on commercial terms.



Structural optimisation

DTU Mechanical Engineering has been a world leader in structural optimisation for more than half a century. This strong tradition has led to a continuous interaction with leading scientists in the field around the world. The research develops methods for size and shape optimisation providing stronger, and weight-saving structures, as well as structures with optimised dynamical properties. Topology optimisation was spun out of the traditional optimisation methods in the late 1980s, providing mathematical methods for structural designs that are unconstrained by human imagination, thus providing designs with freely varying topologies.

The department has many research projects in collaboration with both academia and industries, where the focus is on improving structural designs, for various applications. Furthermore, our researchers build on the experience in optimisation of structural systems, to extend the methods to other fields including fluid flow as well as optical and electromagnetic devices.