Annual Report 2009

DTU Mechanical Engineering
Department of Mechanical Engineering

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ISBN 978-87-90416-30-0

June 2010

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Introduction

After the fusion and reorganization of DTU two years ago, the expectations to the new organization were considerable. Also at DTU Mechanical Engineering the expectations were high, and looking at the result of 2009, the new department must be regarded as a huge success. All measures concerning research, education, economy etc. have been met, and the co-operation inside the department is strong.

The department has now 223 employees including an increasing number of PhD-students covering a wide field of topics in mechanical engineering and materials including several topics in civil engineering.

Many new colleagues, a new organization and many new procedures could lead to some frustration among the staff, and a job satisfaction survey made at the end of 2009 was therefore very relevant.

Nearly 90% of the staff attended the survey which, apart from a high involvement in the department, showed a high satisfactory and only very few points which call for attention.

Although the increase in number of PhD's did not reach the target in 2009, the strategy of employment of new PhD's is a success. At the end of the year there are 70 PhD-students including 12 industrial PhD's.

The co-operation with the industry including co-finance of the PhD-projects is extensive, and the influence of the slowing down in the international economy has fortunately been small. A further increase in number of PhD's is expected in 2010.

A major task in 2009 was the implementation of the international research evaluation. The self evaluation report was prepared in the autumn 2009 but because of time limitations the international panel of highly reputed professors could not visit the department before January 2010.

DTU Mechanical Engineering 2009

All scientific members at the department were involved in the creation of the self evaluation report, and the process was very fruitful and inspiring.

The result of the evaluation made by the international panel was also very satisfactory and showed that the department has several research groups in the absolute international top league and that everybody is doing a very good job.

Another indication of the high quality of research in the department are the many prizes that members of the staff have received in 2009. More about the staff members and the prizes they received is found in "Highlights".

Compared to the turnover of external funding in the years before, 2009 was also a success. New contracts including app. DKK 80 million in research funding of activities at DTU Mechanical Engineering was well over the expectations.

The formulation for a new strategy for thermal energy research and education is under preparation which also takes the increased number of students in energy educations at the department into consideration. The strategy will be implemented in the near future including an increase in the energy activities in the department.

In this Annual Report 2009 the most important results have been highlighted combined with an overview of the activities at the department. I hope that you will enjoy the reading.

Henrik Carlsen
Professor, Head of Department

Highlights 2009

Double triumph for DTU Mechanical Engineering at Shell Eco-marathon.
The winner of the Shell Eco-marathon Europe 2009 is the high school or college student team that designs and constructs the vehicle which goes the furthest distance using the least amount of energy. Both of the cars from DTU Mechanical Engineering won their class and now hold the unofficial world record as well as the titles as world champions in fuel economy.

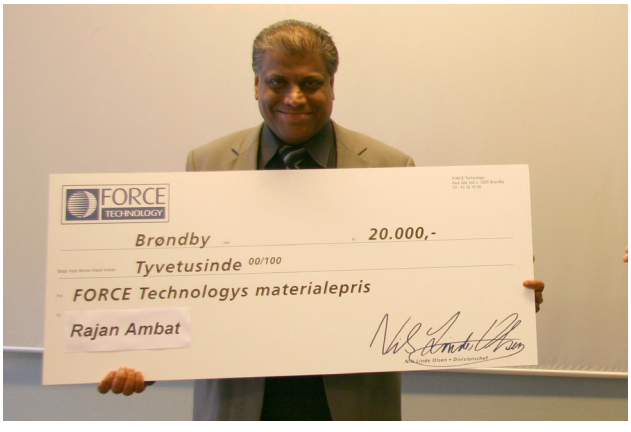
Associate professor Jesper Schramm is supervisor for the student team and he explains: 'Our best year ever! In two years the students have managed to develop a flawless fuel pump and an internal combustion engine with an unparalleled efficiency.

Three years ago we set a target of plus 3,000 km/l for the Prototype class and a position in top 5. Our result this year was 3,549 km/l for the Hydrogen fuelled Innovator vehicle so we have accomplished our goal much sooner than expected. Our other vehicle Dynamo competed in the Urban Concept class. Dynamo reached the world record of 589 km/l! We are of course very proud of the result.'

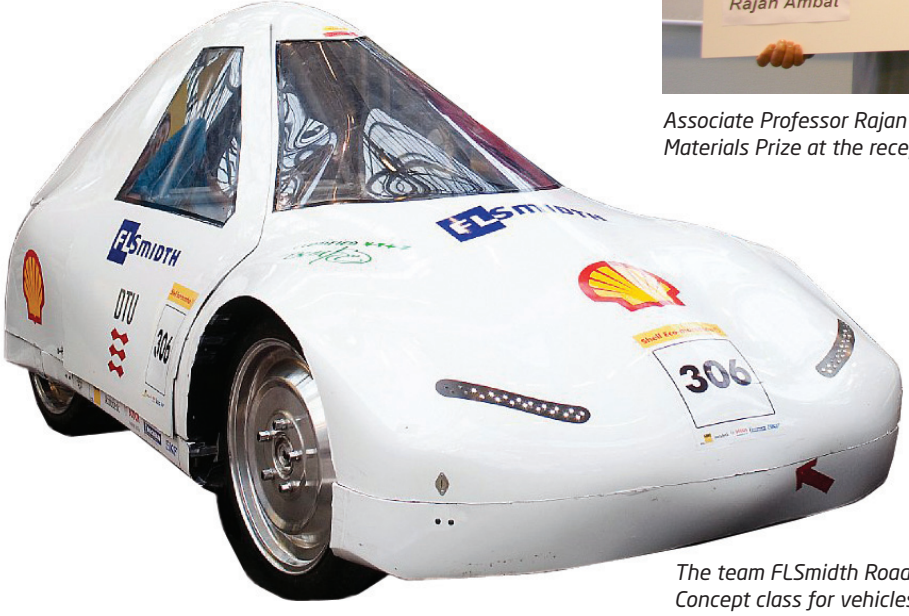
Force Technology prize to Rajan Ambat
Associate Professor Rajan Ambat, Materials Science and Engineering, DTU Mechanical Engineering received the Force Technology's Materials Prize 2009.

The award was given to Rajan Ambat for his research contributions related to "High Resolution Electrochemical Measurements and its applications".

The research interests of Rajan Ambat include Environmental Reliability of Electronic Devices, High Resolution Electrochemical Techniques, and Nano-scale surface modification of Aluminum alloys.



Associate Professor Rajan Ambat with the Force Technology's Materials Prize at the reception at Force held in March 2009.



The team FLSmidth Roadrunners won the first prize in the Urban Concept class for vehicles with an internal combustion engine.

Euromech solid mechanics prize 2009 to Professor Viggo Tvergaard

The prestigious "Euromech solid mechanics prize" is awarded in the field of Solid Mechanics for outstanding and fundamental research accomplishments in Mechanics.

This year the prize and an additional cash reward of EUR 5,000 went to Professor Viggo Tvergaard at DTU Mechanical Engineering.

The award was presented by Professor Werner Schiehlen at the '7th Euromech Solid Mechanics Conference' in Lisbon. The committee summarized the choice of the prominent Danish researcher in the following statement:

"Professor Viggo Tvergaard is awarded for his outstanding contributions to a broad spectrum of Solid Mechanics in particular for his fundamental research on stability of structures, plastic flow localization and shear banding, ductile fracture and creep rupture, and for taking physically based analyses of ductile fracture from an academic discipline to an engineering design tool supported by computational methods".

Jorcks Foundation Prize to Christian Berggreen

Christian Berggreen is associate professor in the field of composite structures and materials within the section of Coastal, Maritime and Structural Engineering and vice-head of the Danish Center for Composite Structures and Materials (DCCSM).

Christian Berggreen was awarded the Jorcks Foundation Prize, consisting of DKK 150,000, as an acknowledgement of his contribution to the research within the focus areas of the structural application of light polymer fibre materials such as glass, carbon and Kevlar.

During his work Christian Berggreen has established a number of research project co-operations with especially the wind power industry and recently the Danish Ministry of Defence where the latter has just funded a major research project with the objective of developing new materials and structural concepts with improved explosive resistance capacity.

Highlights 2009

Sustainable Shipping Award

The Green Shipping Initiative of the Year Award at the first Sustainable Shipping Awards ceremony in London was presented to 'Green Ship of the Future' – a Danish Joint Industry project, aiming at developing and demonstrating technologies and methods for the reduction of air emissions from ships.

The award was presented by William J. Sember (President and Chief Operating Officer, Europe Division, ABS), to Hans Otto Kristensen (DTU Mechanical Engineering) and Thomas Eefsen (Force Technology).

Swift-winged researcher defends his thesis

In December 2009 Wen Zhong Shen, Associate Professor at DTU Mechanical Engineering, defended his thesis, "Computational Aerodynamics and Aeroacoustics of Wind Turbines", which so far is the culmination of his work to describe the aerodynamics and aero-acoustics of wind turbines. Shen began his work on the doctoral dissertation in 1996 when he, after reading a PhD in basic Fluid Mechanics in Paris, came to the DTU and began his career within wind energy research.

"His research combines mathematics and numerics in a very original way that makes it possible to make calculations of things, which were not possible before, such as detailed calculations of noise propagation and aerodynamics of wind turbines," says Jens Nørkær Sørensen, Professor and Head of Section of Fluid Mechanics at DTU Mechanical Engineering, and continues: "This has led to a greater recognition of the physics behind wind turbines."

Shen's calculations partly mean that we can maximize the energy production of wind turbines by improving aerodynamics, and partly that you can control and minimize the noise produced by aerodynamics. This can be quite crucial for the spread of wind turbines and for the competitiveness in the global market as wind turbines become more widespread in urban areas and thus near homes and workplaces.

Wen Zhong Shen, Associate Professor, DTU Mechanical Engineering.

New industrial possibilities through CT-scanning

CT-scanning is the new generation of measuring devices for advanced 3D industrial purposes. The technology is mainly known from the health care sector, but CT-scanning is increasingly becoming the favoured tool in industry for a number of purposes related to product development, processing and product usability.

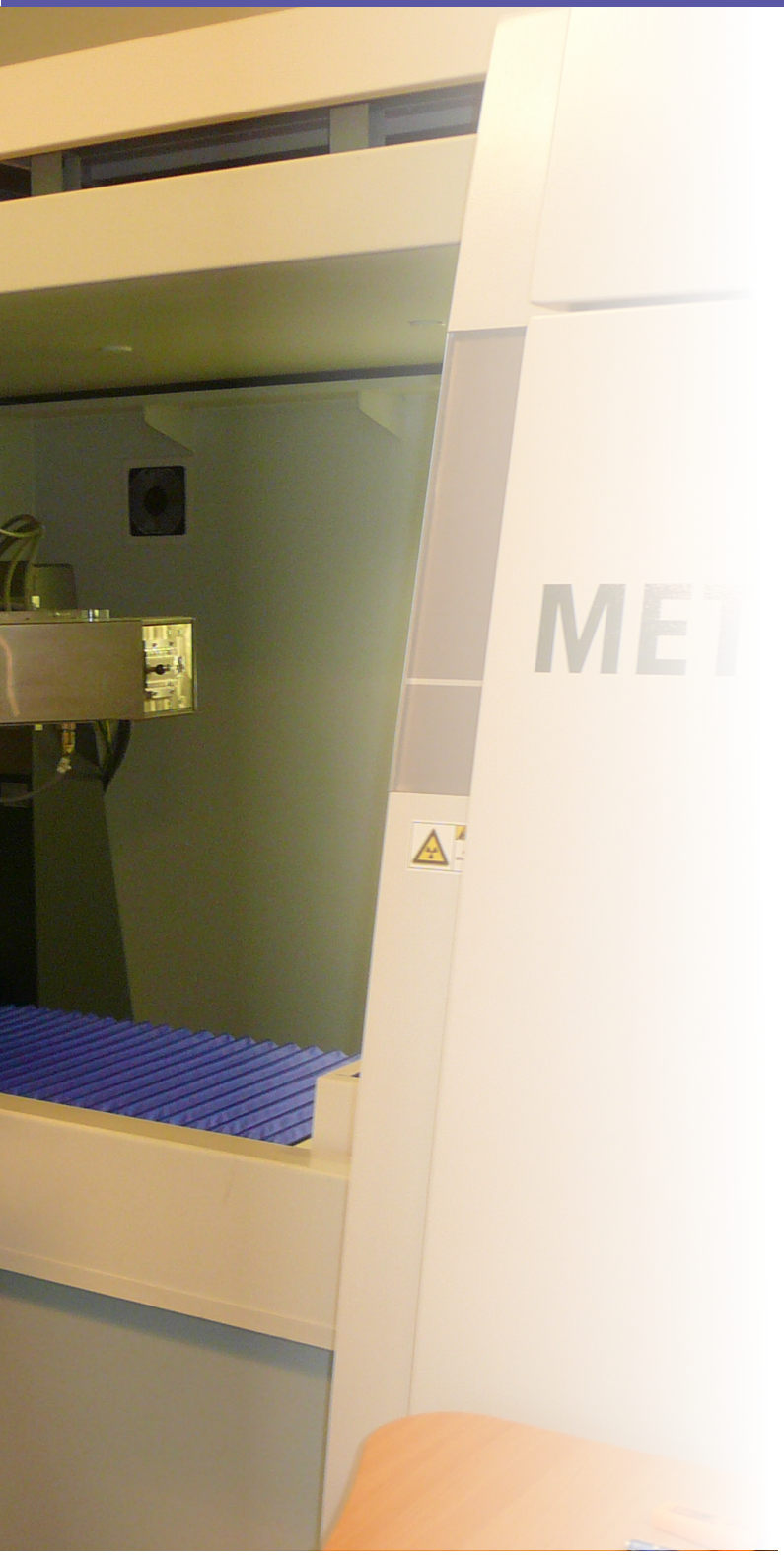
To propel industrial CT-scanning and provide front-end research result DTU Mechanical Engineering and a number of partners established "Center for Industrial Application of CT-scanning - CIA CT: Advanced 3D scanning measurement, quality assurance and product development in industry". The center is headed by DTU Mechanical Engineering and co-financed by the Ministry of Science, Technology and Innovation.

A new industrial approach
The center and the projects arising from the initiative will be of significant importance in many enterprises. Among the immediate beneficiaries are manufacturing industry, pharmaceuticals, electronics, food industry and construction industry but CT-scanning is also relevant to other branches.

The industrial counterparts in the consortium are the two large companies Novo Nordisk and Danish Meat Research Institute and two medium businesses Yxlon and Deformalyze. However, a number of companies have already expressed specific interest to follow the consortium activities on CT-scan. Among these are 3Shape, Construction and Environmental Engineering, Danish Crown, Danish Construction, Danish Sintermetal, Grundfos, Haldor Topsøe, InnospeXion, Kirk Holm, Lego, Noliac, Rockwool, Struer, Tican, Trelleborg and Zebicon. It is estimated that involved producing companies in the consortium and the interest group representing an annual turnover of approx. DKK 2-300 billion.

Professor Leonardo De Chiffre, DTU Mechanical Engineering is appointed as consortium manager and he is responsible to the Ministry of Science. Leonardo is very confident that CT-scanning will have a large impact on the innovation and competitiveness on an even larger number of Danish companies. He explains: "A tool such as the

Professor Leonardo De Chiffre, DTU Mechanical Engineering demonstrates a health care product used for injection of insulin by diabetes patients. Equipment such as this Novo pen is composed of materials of many different types and several tiny elements are embedded. In the future CT-scanning will make it possible to perform a detailed analysis of such a product thus allowing designers to apply improvements at a very early stage of the product development.



Novo pen used for injection of insulin by diabetes patients is a very complex product made up by several very tiny elements and a variety of different materials. CT-scanning makes it straightforward to perform a detailed analysis of such a product and perhaps reveal future improvement possibilities. Thus CT-scanning can help reduce product development time through the ability of technique to influence the design in a very early stage. And the method can be applied and useful in most industrial areas and will lead to overall improvements in community conditions".

Research for industrial purposes
CT-scanning allows revolutionary opportunities but the technology is not yet fully developed. Some of the remaining problems are associated with achievable accuracy, traceability, robustness and usability, especially when it comes to industrial products with close tolerances.

For this reason Leonardo De Chiffre is convinced that the main priority of the research of the project should be focused on the industrial applications of the technique: "Our research will develop new methods, auxiliaries' hardware of calibration, algorithms, software etc. which can help make CT-scan an advanced equipment for coordinate measurement in manufacturing. It can also solve extreme problems with computer speeds and apply CT-scanning to food production."

Entirely new possibilities in terms of sources of beam and signal conditioning will arise and provide new perspectives for investigation of material such as biological tissues and composites. Researchers at CIA CT will help solving issues related to quality assurance and automation and work towards establishing traceability in different materials such as metals, plastics, meat, etc.

Leonardo De Chiffre summarizes: "Several issues are expected to lead to publications in international journals, including development of methods for CT-scan with micrometer resolution in manufacturing, methods for achieving the extremely high computational rates as the basis of CT-scan in food production and research on new sources and methods for signal conditioning as a basis for detailed analysis in biological tissue."

The mastering of Sustainable Energy

The popularity of the new MSc programme in Sustainable Energy has surpassed all expectations. 22 students the first year and 34 students the second are now all in the process of acquiring extensive expertise in one of the most important issues of the future.

Worldwide energy systems will change radically in the next decade and this will cause major impact on society and industry.

The students enlisted at the Master of Science in Engineering (Sustainable Energy) programme gets a fundamental understanding of the limitations and dynamic challenges that lie ahead for the energy sector both nationally and internationally.

Many different elements will affect the effectiveness of energy markets so the participants are trained to comprehend and decode a large variety of sustainable energy challenges.

Record number of students at DTU Mechanical Engineering course
The new MSc programme is a joint initiative from DTU Mechanical Engineering and other departments in close collaboration with Risø DTU National Laboratory.

The Programme consists of 3 mandatory first semester courses and a number of study lines. Head of Section, Associate Professor Brian Elmegaard is responsible for the DTU Mechanical Engineering course line Thermal Energy and he explains: "Apart from the obvious overall relevance of the subject and the excellent job opportunities I believe that one of the attractions of the MSc programme is the successful co-operation between the different departments at DTU. Within the same overall theme the students experience a large variety of scientific and managing traditions at the highest level."

Access to the various study lines is conditional on required entrance qualifications though some of these skills can be obtained during the courses. For Brian Elmegaard it was an additional bonus that approximately half the students from both years have chosen and were qualified to participate in his course in Thermal Energy.

More about the Master of Science in Engineering (Sustainable Energy) programme at:
www.dtu.dk/English/education/MSc_Programs/Sustainable%20Energy.aspx

Brian Elmegaard says: "The students from first year are now busy preparing their thesis and the subjects chosen by the Thermal Energy participant are particularly interesting. The subjects include energy savings for brewing process, optimization and application of industrial heat pumps, integration of solid oxide fuel cells and absorption cooling units, refrigeration system for hydrogen fuelling plant for personal vehicles and solar-driven cooling and heat pumps. And I am pleased to tell that all the thesis work is done with industrial counterparts,which further underlines the potentials of this MSc programme."

More than 50% international students
This MSc opens up many and various job opportunities in industry, government, and research.

Professional tasks include the implementation of sustainable energy technologies within existing or new energy systems, energy system modeling and evaluation of impacts on ecosystems and society.

It is not entirely certain if it is the job perspectives or the content and focus that appeals to the students but it is a fact that news of the new programme has travelled fast.

More than 50% of the applicants are international students and they come from all over the world.

One of the international participants at the MSc programme is Antoine Frein from France. He did his bachelor at Nantes-Centrale but when he learned about the new Master course at DTU he decided to leave for Denmark.

He says: "I knew that Denmark was world leading in sustainable energy and in thermal energy research, which is my favourite subject, so when the possibility of a scholarship appeared I was on my way. It was a pleasant surprise to join my student colleagues at the course. There is a much more serious and mature approach to the courses than I was used to in Nantes and though French universities are very strong on the theoretical parts of engineering I think the Danish tradition for real life practise and focus on applications is a huge advantage".

Associate Professor Brian Elmegaard

Teaching programme

Studies at DTU Mechanical Engineering
DTU Mechanical Engineering offers teaching programmes and courses at undergraduate, graduate, and PhD levels.

The very comprehensive teaching programme covers energy systems, fluid mechanics, material and structural mechanics, coastal engineering, naval architecture, materials science and engineering, and manufacturing engineering.

DTU offers three separate teaching programmes in engineering:

- 3.5 years Bachelor of Engineering (BEng) programme
- 3 years Bachelor of Science (BSc) programme
- 2 years Master of Science (MSc) programme.

DTU Mechanical Engineering is responsible for a considerable part of the education in mechanical and energy engineering as well as materials and manufacturing engineering.

DTU Mechanical Engineering studies

International Master Programmes
DTU Mechanical Engineering contributes very actively to five of DTUs international MSc programmes:

- Civil Engineering
- Engineering Design and Applied Mechanics
- Materials and Manufacturing Engineering
- Sustainable Energy
- Wind Energy.

The contribution to the programme in "Civil Engineering" became more visible in 2009 as the study line "Civil Works and Marine Structures" were formulated within the programme. Also a revision of the former programme in "Materials Engineering" took place in 2009 and resulted in the programme in "Materials and Manufacturing Engineering", while "Sustainable Energy" started as a new DTU MSc programme in 2008 and the first candidates are expected to graduate in 2010.

New Nordic Master Programme
DTU Mechanical Engineering was in 2009, together with relevant departments from Aalto University in Helsinki, Finland, Chalmers in Göteborg, Sweden, KTH in Stockholm, Sweden, and NTNU in Trondheim, Norway, granted funding from the Nordic Council of Ministers for establishing an international MSc programme in Maritime Engineering.

The five universities form the Nordic Five Tech alliance and the Nordic Master in Maritime Engineering will be based on the expertise of the Nordic Five Tech universities within naval architecture, offshore engineering and maritime engineering. The programme will be coordinated by DTU Mechanical Engineering and it is expected to start in the autumn of 2011.

Wind turbines on new ground

"At DTU Mechanical Engineering we have for several years worked focused with simulation tools and modelling of aerodynamic design of wind turbines.

Our close cooperation with Risø-DTU has now made it possible to combine aerodynamics with atmosphere physics and thus generate detailed images of the wind conditions in which the turbines function in actual.

This possibility is the background for the creation of the "Center for Numerisk Vindmølle Aerodynamik og Atmosfære Turbulens" (Centre for Numerical Wind Turbine Aerodynamics and Atmosphere Turbulence) as well as the grant of DKK 32 million from "Det Strategiske Forskningsråd" (The Danish Council for Strategic Research)," Professor of fluid mechanics, Jens Nørkær Sørensen, DTU Mechanical Engineering, explains.

From simulation to application
Jens Nørkær's research team develops computer programmes that are particularly well-suited for explaining several questions of flow in the field of wind energy. One of the factors that for several years has made Denmark a leader in this field are these programmes and according to Jens Nørkær, both the research and the Danish wind turbine industry will also in the future be in the lead by focusing on the exchange of knowledge and ideas.

He says: "As researchers we are often interested in the long-term perspective and with the creation of the "Center for Numerisk Vindmølle Aerodynamik og Atmosfære Turbulens" we will have a framework which ensures that focus is both on the long-term perspective and on the use of the industry of our research. Significant users of the research of DTU on aerodynamics such as Vestas and Vattenfall are in fact also active partners of the centre and their participation makes it possible to test new initiatives in practice."

Jens Nørkær Sørensen
Professor Jens Nørkær Sørensen, DTU Mechanical Engineering, heads the new "Center for Numerisk Vindmølle Aerodynamik og Atmosfære Turbulens". One of the priorities of the centre is to contribute to ensuring Denmark an optimal, low-cost and independent production of energy.

Swedish forest
Sunset in a Swedish forest lake. The "Center for Numerisk Vindmølle Aerodynamik og Atmosfære Turbulens" has been asked by the wind power developer Vattenfall to analyze the conditions of aerodynamic and micro-climatic nature that can influence a turbine blade in a forest area such as this.

Jens Nørkær and his colleagues at DTU are well under way with developing next-generation simulation tools for aerodynamic design of wind turbines. It is not least the ability of these new tools to shed new light on the effect of the wind on turbines placed in very complex terrain that is interesting. Current debate has once again created awareness of the often unpopular combination of wind turbines and residential areas.

With future possibilities of constructing even more effective giant wind turbines, an increased pressure on politicians and industry for finding locations that limit nuisance as much as possible is anticipated, and here the "Center for Numerisk Vindmølle Aerodynamik og Atmosfære Turbulens" can play a key role.

Geography must be considered in the design

Besides the obvious possibility of placing future wind turbines in offshore wind farms there will be a need to look thoroughly into possible locations in arctic areas, forests and mountains, and therefore it must be possible to examine the special wind conditions in such locations in detail. The continued research of optimization and analysis of the aerodynamics of the blades must to an even greater extent be combined with simulation tools that consider the significance of the geographic and physical location of the wind turbines.

Jens Nørkær says: "It is more likely that we will be able to place wind turbines in all kinds of terrain and in complex wind conditions, and we will be able to place them closer together in the future. This will be feasible, as our study will make it possible to design turbine blades so they are perfectly suited for the geographical and topographical conditions they will be exposed to. The "Center for Numerisk Vindmølle Aerodynamik og Atmosfære Turbulens", for example, will soon commence research into the special micro-climatic conditions in certain Swedish forests in order to install specially designed wind turbines there."

The expanite process
- A breakthrough in surface hardening of stainless steel

The surface of stainless steel is covered with a thin oxide film which protects the material and makes it corrosion resistant. The oxide film acts as a barrier for the transfer of carbon and/or nitrogen atoms to the metal and prevents straightforward surface hardening of stainless steels.

Now researchers at DTU Mechanical Engineering have launched a patent applied for process that enables an effective removal of this protective oxide layer, which then allows a fast and efficient surface hardening of stainless steel and titanium alloys.

A new company in charge of the technology
At DTU Mechanical Engineering the researchers behind the invention are testing the method on various items and on a variety of products and materials. Professor and Head of Section Marcel Somers, Senior Scientist Thomas Christiansen and PostDoc Thomas Hummelshøj have established the company Expanite based on the patented applied for process and they use modified annealing furnaces to apply the method.

Several companies are involved in testing the suitability for their products to the Expanite process in a Proof of Concept project granted by the government in order to examine whether this new technology may be used to improve their product features.

Marcel Somers explains: "The Expanite process is highly generic and functions on ordinary and stainless steel as well as on titanium. Compared to other processes, the treatment time is competitively shorter. Moreover, since our process is a gas process the implementation technology is widely available. We are now busy testing the technique on all kinds of products. Food processing, paper fabrication and medical applications are just a few examples where production equipment has to be corrosion as well as wear resistant. Our process is likely to be of great interest to numerous companies worldwide and the establishment of Expanite makes it possible for us to assist such companies on commercial terms. Our process is more versatile, faster and cheaper than the current alternatives."

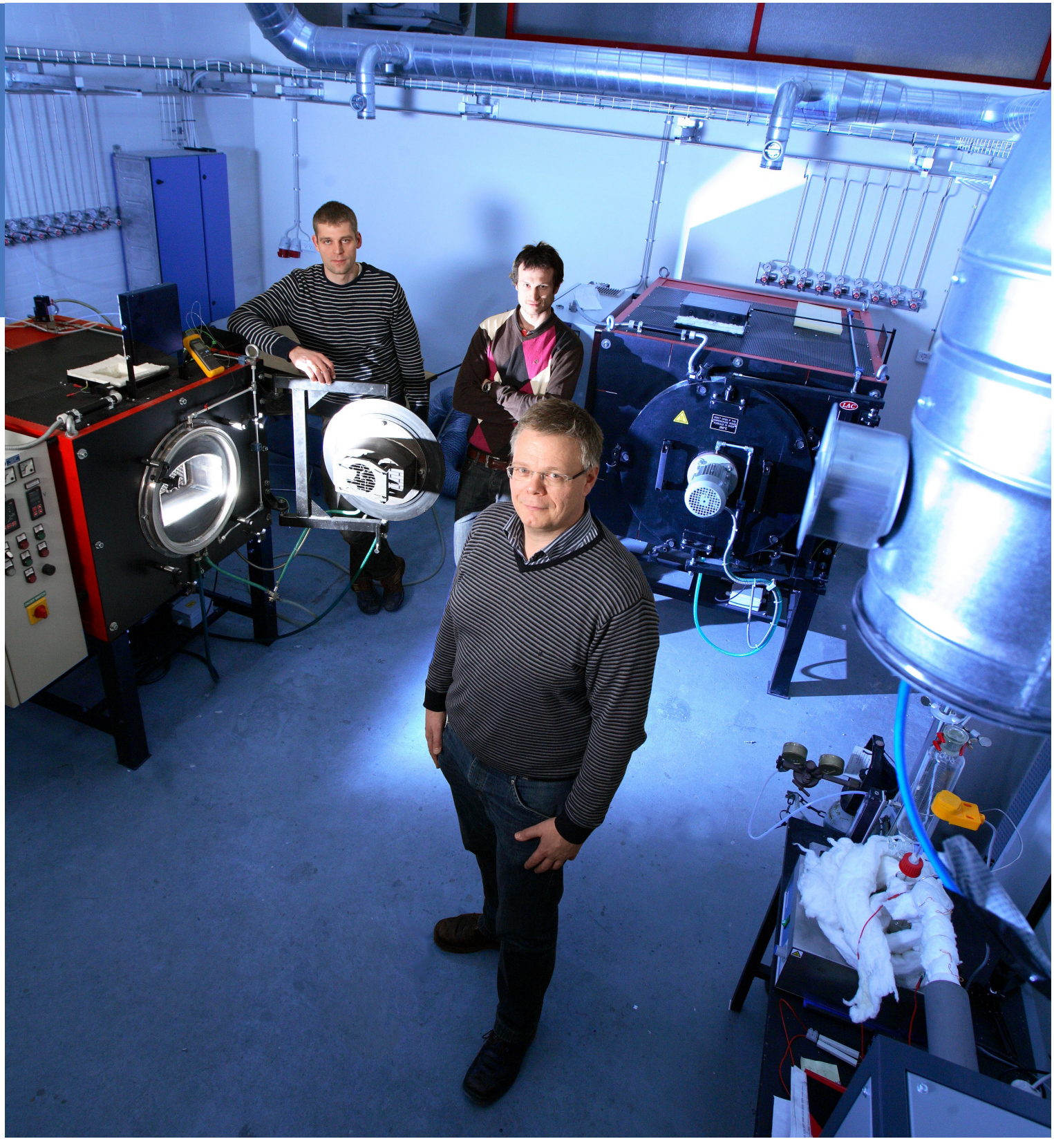
The home appliance industry is one of the largest consumer product industries in which stainless steel is widely used to prevent corrosion. However, erosion of home appliances is a problem because it deteriorates their appearance. Examples are refrigerators, stoves, sinks, kitchen tables, wash basins, cookware and cutlery.

Revolution in surface hardening methods
Many types of stainless steel meet the need for corrosion resistance but their relatively low hardness often results in accelerated wear and materials loss. Since these materials can not be hardened by conventional heat treatment without reducing corrosion resistance it is common to make design allowances for repair and/or replacement of equipment, even though this is far from the ideal solution. PostDoc Thomas Hummelshøj is appointed as the first CEO of Expanite.

He explains:"Even before the Expanite technology it was indeed possible to achieve surface hardening of stainless steel. However, the process was restricted to relatively costly niche products such as key components in nuclear power plants, aerospace and fasteners in marine and defence equipment, all expensive and critical parts which do not tolerate failing.

It was complicated, expensive and time consuming to remove the protective oxide layer covering the stainless steel which prevents a straightforward method for surface hardening. Delivery time for the treatment was anywhere from 3 weeks to several months and items with complicated topology were almost impossible to process. With our new technology you just have to add the right gas and use the right temperature and furthermore, you are able to treat any kind of subject within a few hours."

Senior Scientist Thomas Christiansen has been working on the process for several years first as a student at DTU Mechanical Engineering and since as a member of the research staff at the department: "It is a great relief to reach Proof of Concept after all the time and effort. Our patent pending process goes behind and further than the technology previously used.



The Expanite treatment involves an effective removal of the protective oxide film on top of the stainless steel. This allows an incorporation of carbon or nitrogen atoms in the underlying metal within comparatively short treatment times. After ended treatment the protective oxide layer is re-established automatically. The result is a resistant and practically scratch free surface.

It really is a breakthrough in gaseous surface engineering and a complete revolution in the way surface hardening of stainless steel is made. Apart from this we are worldwide recognized for our generic research work in this field, which has been published in the last 6 years. A very good example that fundamental research and innovation go along."

Coastal, Maritime and Structural Engineering

Research activities

Hydro-elasticity of ships
The elasticity of the hull girder of a ship is becoming more important today with the increasing size of ships and the use of high tensile steel. In cooperation with UC Berkeley hydro-elastic effects are studied for large container ships with regard to fatigue damage and ultimate loads.

Considerations are given to both impulse loads (whipping) and steady-state wave induced vibrations (springing) including 3D effects.

Operation of marine structures
An onboard system for guidance to ship masters on optimum course and speed based on automatic monitoring of sea states is developed. It includes a probabilistic prediction of hull girder stress spectra and ship accelerations and motions.

Furthermore, fault tolerance is implemented in the system. Two related projects deal with the establishment of mathematical models for fuel consumption and emissions from shipping.

Wave induced loads on offshore wind turbines and wave energy converters
Ongoing work over the past five years has led to the development of an efficient numerical solution for predicting the nonlinear wave climate in the coastal region and estimating the subsequent loads on coastal and marine structures.

Several projects have been initiated in 2009 to extend and apply this model to the analysis of both fixed and floating structures in the marine environment, with particular focus on wind turbines, and wave energy converters.

The goal of these projects is to provide design tools which can accurately predict both the ultimate loads and the lifetime fatigue loading; as well as the induced motions of these structures.

Hydrodynamics and sediment transport in Scour Protection Layers around offshore wind turbines.
We have studied how stable a local protection of cover stones will be. These cover stones should prevent the underlying sand close to the tower to move, but field data from e.g. Horns Rev indicate that this will not be the case: settling of up to more than one meter is observed of the protection layer.

We are studying how the fine sea bed material are being moved and sucked up through the cover stone layer, where the flow is introduced by the waves and current outside this layer. Also the hydro-dynamics outside the stone protection layer is studied to evaluate the stability of the cover stones.

The dynamics of transient waves related to tsunamis
A consensus of using solitary wave theory as a description of tsunamis has prevailed in the tsunami community for quite a while. As a consequence, laboratory tests (and analytical treatment) of the run-up, the scour, the wave impact and the boundary layers in connection with tsunamis have to a large extent been conducted by using solitary waves as a model of the incoming tsunami.

Nevertheless, we have recently concluded that this paradigm is completely wrong as time- and space-scales of geophysical tsunamis are totally different from solitary waves.

Damage tolerance and assessment of sandwich composites
Cyclic fatigue loading of sandwich structures with interfacial damages, eg. face/core debonds, is especially in focus, and the section is leading an international network (SANTIGUE) developing characterization and analysis tools able to assess damage tolerance and residual lifetime of debond damaged sandwich structures.

New generalized mixed-mode governed crack growth rate laws for sandwich face/core interfaces have been measured

The research topics at the Section for Coastal, Maritime and Structural Engineering deal with coastal engineering, maritime engineering, naval architecture, structural engineering including risk and reliability assessment and environmental issues like reduced energy consumption and emission from ship.

Theoretical, numerical and experimental investigations are carried out using state-of-the-art tools for the design, analysis and operation of large maritime, coastal and land-based structures under environmental loads, such as waves and wind.

Photo: Felix Weber

in a specially developed sandwich Mixed Mode Bending test-rig, using a constant energy release rate approach. General fracture mechanics based numerical crack propagation and residual lifetime prediction models based on the measured crack growth rate laws are being developed and validated, in order to be implemented in structural reliability based damage assessment tools for specific structural applications.

Wind turbine blades with passive control through composite material tailoring:
There is a high interest to apply active or passive systems in the blades which are able to reduce especially the fatigue loading. Passive systems are robust with regard to load fluctuations and typically less complicated to implement in blade designs.

This objective is being pursued on several fronts, including development of anisotropic beam elements able to include the structural effect of bend-twist coupling driven deformations in aero-elastic analyses, optimization schemes able to account for design tailoring of layup configurations and finally numerical implementation and experimental validation of coupling effects in future wind turbine designs.

Vibration control of structures
Two approaches to vibration control of structures have been investigated: resonant control and the use of controllable dampers. Resonant control is a general form of the principle known from the classic tuned mass damper, where a suspended mass oscillates in resonance, and permits damping to be introduced via the relative motion of the mass.

A theoretical framework has been developed for resonant damping of damped structures under stochastic load and extended to general control systems with displacement or acceleration feedback. Control strategies have also been developed for the use of friction or magneto-rheological dampers to control variable amplitude response.

Thermal Energy Systems

Research activities

Propulsion systems for large ships
Until recently very few environmental regulations existed for the shipping industry; however, currently drastic legislative actions are taken on global and national levels. In a Danish context, the merchant navy is responsible for CO_2 emissions of similar magnitudes as those of the rest of the society.

The research at the department is aimed at designing prime mover concepts for ships that reduce the environmental and human health impacts compared to the engines of today, including economical, legislative and practical considerations.

Concepts considered include slow-speed, two-stroke diesel engines with waste heat recovery systems as well as gas and steam turbine combined cycles. As for the waste heat recovery systems, both conventional steam cycles and cycles based on alternative working media are considered.

The basis for the research is advanced thermodynamic simulation models, which are used to design and optimize novel prime mover systems. In addition, they are used to develop more simple tools that can be used by the shipping industry to improve the performance of existing machinery.

Fuel cells
Solid oxide fuel cells (SOFC) work at very high temperature levels (700-800^0 C) and they are interesting for CHP applications (up to 1 MW) as standalone plants.

Different plant concepts with different reforming processes as well as different fuels are under investigation.

Due to their operation temperature SOFCs are also interesting in combination with other traditional technologies such as gas turbines, steam turbines and stirling engines for CHP applications.

Different power classes from a few kW and up to large MW classes are possible to design with very high electrical efficiencies (50-70%). In a project we are studying the possibilities of combining biomass gasification with an SOFC plant.

PEM fuel cells work at low temperatures of about 70-100^0 C which are suitable for a variety of applications such as transportation, forklifts, mobile phones, etc.

In a project financed by Danish National Advanced Technology Foundation we are investigating a PEM fuel cell based plant for transport applications. Different aspects are studied, such as efficient cooling loops and efficient possible fuel recycling methods.

Modelling and optimization of evaporators
In both refrigeration systems and power plants the evaporator is a central unit. Its design influences operation and efficiency significantly.

We study details of refrigeration evaporators for both conventional refrigerants and modern natural refrigerant, e.g. CO_2.

In power plants the evaporator is a central part of the boiler, new evaporator layouts improve design and performance of the boiler, but also require new control system design.

Biomass utilization for combined heat, power and fuel production
Biomass is an important renewable energy resource. We work on system optimization for production of heat, power and biofuel. System optimization is based on advanced thermodynamic methods such as exergy and thermoeconomics.

We work in close cooperation with other groups who develop biomass gasifiers and fuel cells.

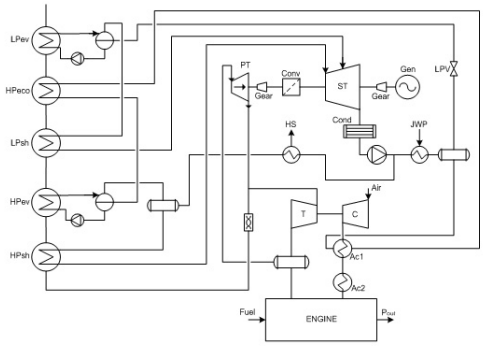
The research in thermal energy engineering is divided into six areas:
Thermal energy systems modelling, simulation and design. We are actively developing advanced tools for analysis and optimization with emphasis on process optimization, energy efficiency, exergy methods and automatic control.

Power production processes: Steam turbines, gas turbines and fuel cell systems. Research activities include energy optimization of propulsion systems for large ships, analysis of fuel cell systems, and compressed air electricity storage.

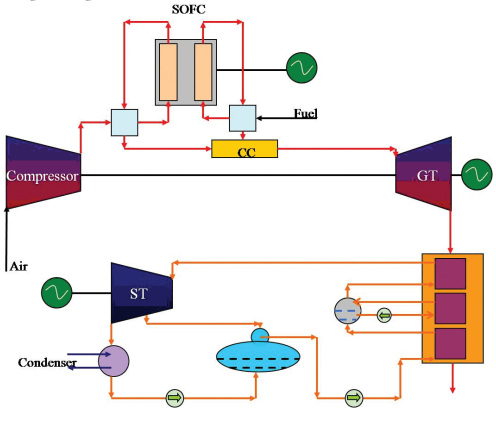
Refrigeration, heat pump technology and Industrial energy savings. Refrigeration activities centre on new refrigerants and process integration in refrigeration systems. We are active in developing new solutions that are optimal from an overall point of view.

Biomass for power and fuel production. The work is focused on processes for integration of production of power, heat and biofuels.

Marine diesel engine with waste heat recovery system.



Fuel cell based power plants



Materials and Surface Engineering

Research activities

The first interaction of the environment with a material is the surface, irrespective of whether this interaction is mechanical, chemical or biological in nature.

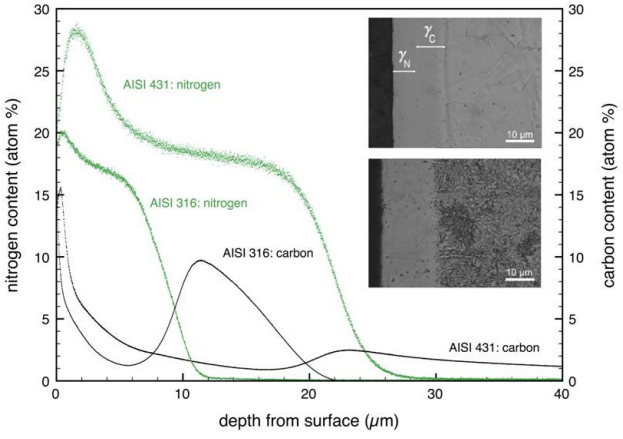
Improvement of materials performance with respect to corrosion, wear and fatigue is therefore often realized by modifying the surface. Surface engineering is the major materials synthesis activity in the section and for this purpose electrochemical, thermochemical and PVD techniques are applied and further developed.

In particular the expertises in thermochemical and electrochemical surface engineering are considered to be at a leading international level. The research activities in surface engineering cover the entire chain from basic research of generic importance to applied research, engineering and innovation.

Applied research in surface engineering is largely conducted in combination with the design of special surface properties for enhanced functionality. Among the functional surfaces of current interest are self-cleaning paint, realised by the incorporation of photo-catalytic material (for aviation applications), easy-release coatings for contact frying (for food industry), anti-microbial surfaces (food and medical applications), low temperature proton exchange membrane fuel cells (energy generation).

Among the generic research activities are the use of nano-technology and plasma techniques for surface engineering of aluminium alloys as well as the stability of nano-crystalline electrodeposits. Research in and development of thermochemical surface engineering focus on low temperature gaseous surface hardening of stainless steel by the incorporation of nitrogen and/or carbon to improve the wear and fatigue performance of stainless steel while maintaining the corrosion performance.

The research activities in this field are internationally leading, both from a theoretical point of view as well as from a point of view of developing new technologies and acquiring and licensing/selling IPR.



Microstructure stability and phase transformations
Materials microstructure evolution during processing as well as during application lies at the very essence of understanding the relations between process parameters, properties and performance. Understanding the occurring phase transformations in materials form the basis for materials modelling activities.

Among the generic research activities are the development and further refinement of analysis techniques for micro-structure investigation with microscopical, diffraction and spectroscopical techniques.

Electron microscopical techniques have gone through a revolution in the later years and have facilitated the recording of large amounts of data at higher resolution.

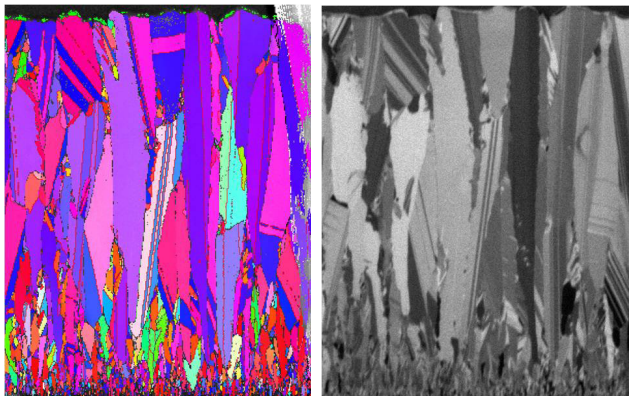
Tomography and 3D reconstruction of series of 2D images allow an unprecedented detailed examination of materials, particularly in combination with spectro-scopical and crystallographic investigation in 3D (3D EDS and 3D EBSD). Particularly, the application of 3D EBSD in materials research on grain boundary engineering and characterisation of phase transformations in electro-deposits is a demanding research challenge, and illustrates what is currently on the verge of being feasible.

The research in the section concerns all aspects of materials and surface engineering: synthesis, microstructure, properties and performance. Research topics span from fundamental to applied and involve both experimental and modelling aspects. Particular emphasis is put on surface engineering, materials in energy generation and storage as well as materials deterioration mechanisms by chemical, mechanical and thermal contact with the environment.

A wide variety of research facilities for materials synthesis, microstructure characterisation by microscopical, spectroscopial and diffraction techniques is available. Also facilities for materials performance testing from macro to micro-scale are available.

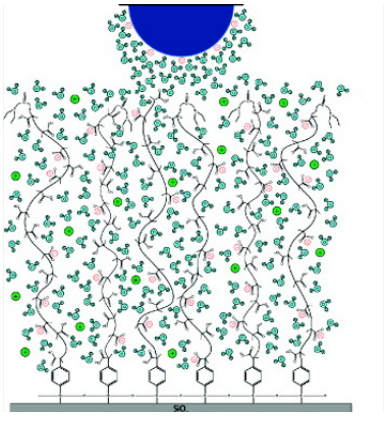
Microstructure stability assessment and estimation of life expectancy of metallic materials in power stations are a 30+ year successful collaboration and have received strong international scientific and industrial attention.

This field of research is based on a combination of experimental investigations of the microstructure and modelling the thermodynamics and kinetics of phase transformations in martensitic 9-12% Cr steel and coated Ni-based superalloys. Research of generic importance is the role of mechanical stresses on phase transformations and microstructure stability.



Materials performance and degradation
Research in materials performance and materials degradation is concentrated on corrosion, tribology and high temperature performance (creep and corrosion), i.e. the chemical, biological, mechanical and thermal interaction (or combinations thereof) of materials with the environment. The strategy is to investigate, identify and understand the degradation mechanisms that affect the performance of materials and to use this understanding as input for the life expectancy and design of improved materials solutions, for example by surface engineering.

Corrosion degradation of materials is investigated in atmospheric, aqueous, biological and high temperature environments. Research on the development of microscale and high resolution characterization techniques of the electrochemical properties were developed and are applied in the Centre of Corrosion in Electronics (Cellcor). This centre focuses on the environmental reliability of micro-electronics. Wear of macroscopic surfaces is an important but complex degradation mechanism, because often the interaction is assisted and aggravated by other degradation mechanisms. In this respect we have in the later years worked on massive wear in vertical roller mills for milling of raw materials for cement production, tribocorrosion in food industry applications and tribocorrosion of hip implants.



These investigations have in a series of cases provided the inspiration to propose improved materials solutions, e.g. by surface engineering. With the recruitment of a new assoc. professor in 2009, the section has initiated research in nano- and biotribology.

Highlights in 2009
- Employment of faculty member Seunghwan Lee to initiate research in bio- and nanotribology
- Installation of glow discharge optical emission spectroscopy facility for composition analysis of surface engineered materials
- M-prizes to two M.Sc. project students: Uffe Bihlet and Jesper Lund Madsen for two independent projects related to High Temperature Materials.

Fluid Mechanics

Research activities

Swirling flows
Several flows in with rotation (swirl) in confined geometries are studied experimentally using Particle Image Velocimetry. Practical applications are the scavenging flow in a two-stroke Diesel engine and the flow in a spray-dryer chamber. The vortical flow structures are described and compared to mathematical models. The flows are difficult to simulate with turbulence models and the experiments therefore also guide new methods for simulations.

Shape optimizations of wind turbine blades
A new design tool for optimizing wind turbine blades and airfoil sections has been developed. The design tool is based on an aerodynamic/aero-elastic model that includes the structural dynamics of the blades and uses blade-element/momentum theory. The main aero-elastic behaviour of the wind turbine is modeled using 11 basic degrees of freedom.

Wind power in Greenland
Together with Arctic Technology Centre a 6 kW wind turbine has been installed and tested in a small village west of Sisimiut.

Stability of tip vortices
A comprehensive study has been carried out to investigate the stability of tip vortices. The analysis is based on the simulation of Navier-Stokes equations using the actuator line technique. The stability is investigated by following the propagation of the amplitude and the phase of imposed perturbations. The analysis enables to quantify the influence of free stream turbulence on the stability of the vortices.

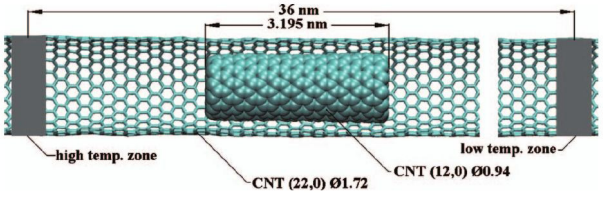


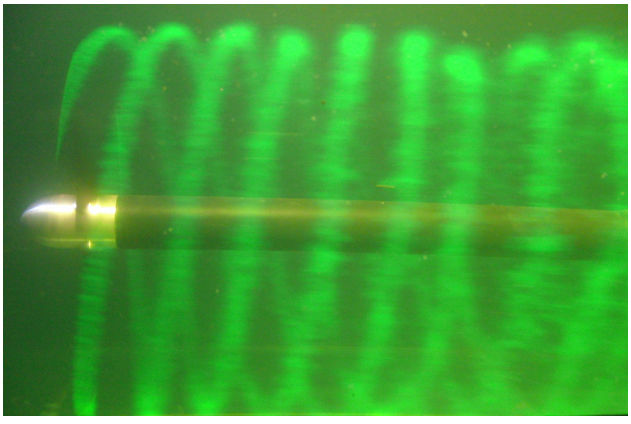
Illustration of carbon nanotube motor.

Model experiments of the wind turbine wakes
A pitch-regulated model rotor of diameter 40 cm has been designed and tested in ISVA's water channel. Visualizations have been carried out by coating the blades by flourescein which during operation is dissolved into the wake.

After-treatment of engine exhaust
Different diesel particulate filter solutions are investigated experimentally and theoretically. The parameters investigated are, among others, filter temperature, fuel sulphur tolerance, needed fuel additive and allowed filter pressure drop.

Alternative fuels for internal combustion engines
Application of alternative fuels in IC Engines is investigated in several collaboration projects. The purpose is to evaluate the future of ethanol as a fuel for IC Engines in connection with road transportation.

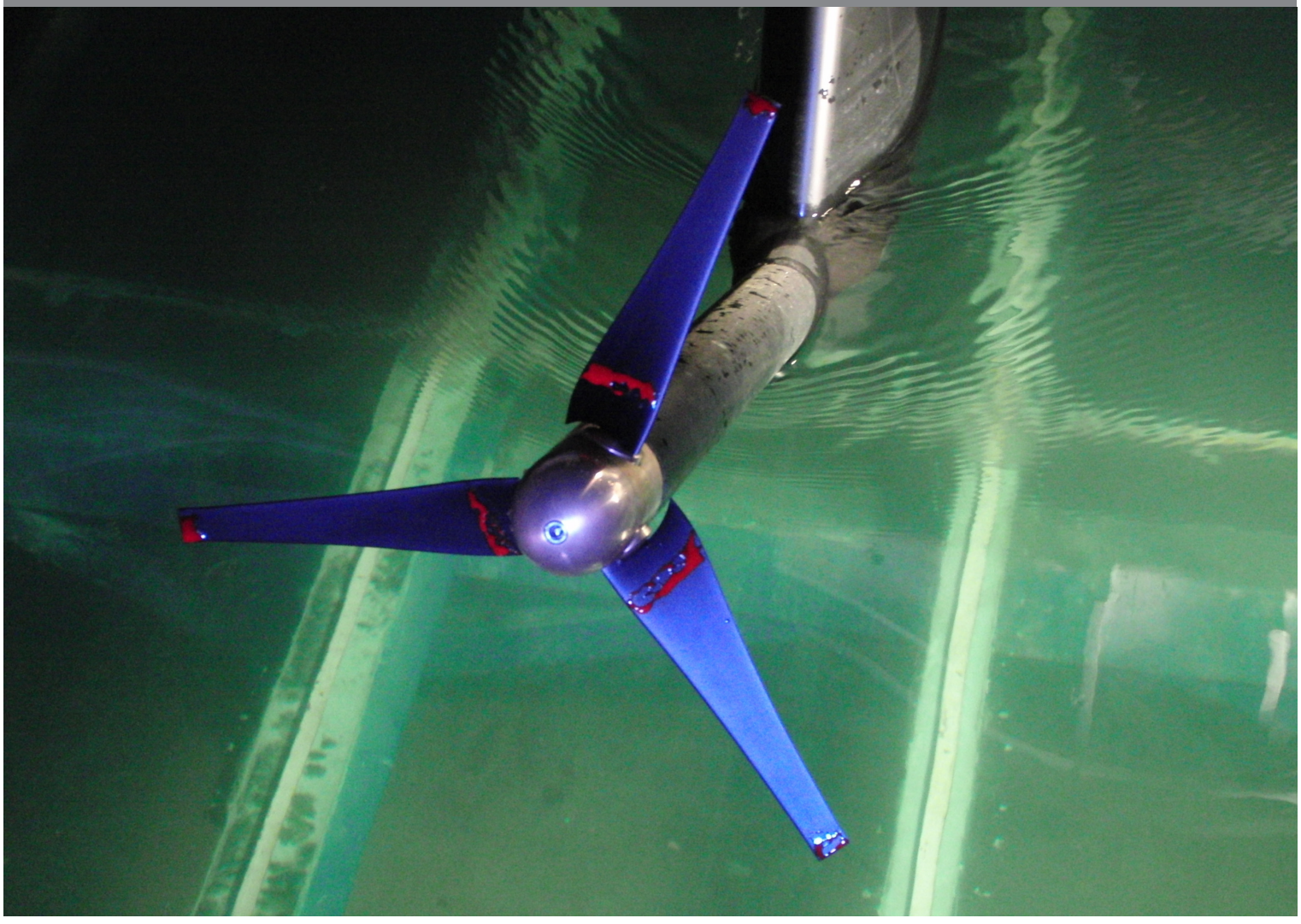
Noise and aero-acoustics
New compact high-order discretization schemes and optimization algorithms have been developed to study and reduce aerodynamically generated noise from airfoils and wind turbine rotors. Computations using the new scheme show very good agreement with measurements.



Visualizations of tip vortices.

The research topics of the Fluid Mechanics Section focus on basic fluid mechanics with main applications directed towards aerodynamics of wind turbines, combustion engines and flow-related industrial process equipment. Fundamental research in fluid mechanics includes laminar-turbulent transition, aero-acoustics, rotating flows, mixing of fuels, room convection, nano- and mesoscale fluid dynamics, and biological flows.

The research is carried out using Computational Fluid Dynamics (CFD), employing in-house developed and commercial computing codes, and experimental fluid mechanics (EFD), using mostly optical methods, such as Laser Doppler Anemometry (LDA), Particle Image Velocimetry (PIV) and related techniques.



Model of wind turbine rotor

Simulation of wakes and wind farms
The mutual influence of wakes of turbines grouped in wind farms is studied using Large Eddy Simulations. The simulations are utilized to derive expressions for mean deficits and turbulence inside wind farms. This type of modelling is extremely crucial for the further development of offshore wind energy.

Biological flows
The flow induced by suspension feeding bivales (e.g., Mytilus Edulis) is studied using Particle Image Velocimetry and three-dimensional partice vortex methods simulations are performed to study biomixing and the flow induced by self propelling jellyfish. The work is performed in collaboration with University of Southern Denmark and ETH Zurich.

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Manufacturing Engineering

Research activities

Research themes
All research activities of the section are characterized by a combined modelling and experimental approach, where manufacturing metrology plays a major role.

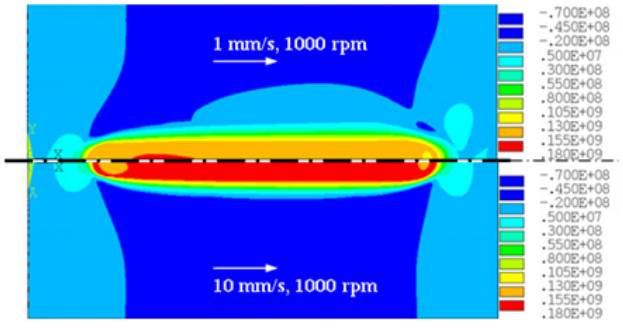
The research is based on the following methods:

- Process analysis (including analytical and experimental process descriptions and investigations)
- Process modelling (including integrated and multi-physics modelling as well as optimization methods)
- Testing and modelling of materials properties and tribology
- Metrology (including dimensional and geometrical metrology and process metrology).

Material testing is an integrated part of the process chain development providing characterization data for structural design and process simulation.

The technologies covered by the section include metal forming, polymer processing, casting and welding.

Furthermore, micro manufacturing is considered a special technology area due to its special characteristics (covering the above mentioned process technologies as well as mechanical and thermal material removal processes).



Micro manufacturing
The research activities are focused on concurrent development of materials, process technologies and production systems to support industrial production of micro mechanical systems.

This includes the development of complex process chains to realize multi-material micro products based on replication processes (e.g. injection moulding and metal forming) and the corresponding tooling technologies.

Research involves process characterization and simulation, process chain integration including assembly and quality control of micro mechanical systems as well as product development methods for micro scale.

Process modelling.
Although being applied as a valuable tool at user level by almost all researchers at the section, process modelling as a research area in itself is a separate theme.

The basic philosophy of the research follows two pathways:

- A more basic science oriented pathway with the aim of describing and modelling the basic physics of the considered processes at a sufficient level for understanding their nature and being able to predict their influence on the final manufactured products.

- A more application oriented pathway, which based on the models as described above, aims at being able to improve and optimize the manufacturing processes with numerical simulation tools, thereby achieving enhanced products regarding choice of process, materials, geometry, etc.

The research of the section covers manufacturing engineering in a broad sense. The research involves theoretical, numerical and experimental approaches. The main activity areas cover a wide range of manufacturing processes, micro/nano manufacturing, metrology on all scales as well as modeling approaches to all these subjects.

The objective of the research activities of the section is to promote "Precision Manufacturing" to meet requirements to modern products in terms of high performance, durability and reliability, as well as size and cost efficiency. Research is based on a multi-disciplinary use of process technology, materials science, thermodynamics as well as solid and fluid mechanics in the analysis and modelling of manufacturing processes.

Metal forming and tribology
The metal forming theme focuses on experimental and numerical analysis and modelling of cold forging of steel, stainless steel and aluminium, rolling including skinpass rolling, mechanical processing of superconductors, sheet metal forming including deep drawing, hydroforming and Single Point Incremental Forming (SPIF).

Metal forming tribology is focusing on testing and modelling of friction, lubrication and wear in metal forming. Joining activities earlier focused on cold welding are now concentrated on resistance welding.

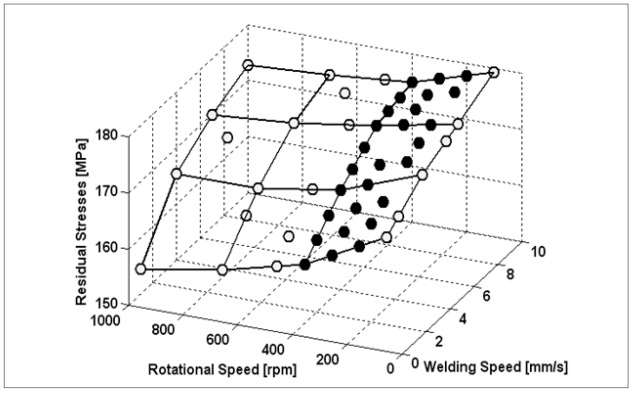
Special focus is directed towards analysis and modelling of welding of advanced high strength steel and micro components and testing and modeling machine dynamics.

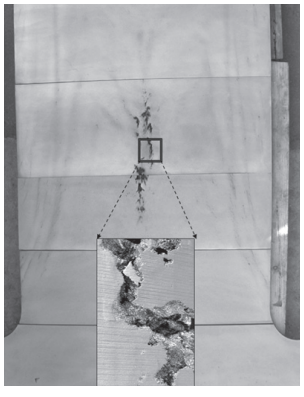
Metal casting
Metal casting of complex and optimized components is another research theme. This area stands on two legs: materials engineering and optimised production methods.

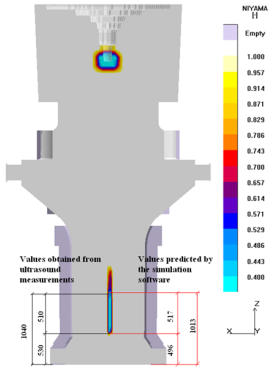
The material part is conducted in close collaboration with section on Materials Science and Engineering, and the optimisation part in close collaboration with the process modelling group.

Manufacturing metrology
Geometrical Metrology activities concern development of methods, equipment and artefacts for analyses based on functionality related and traceable measurements of products, manufacturing processes and production equipment.

Main research topics are:
- surface metrology
- coordinate metrology
- process metrology.







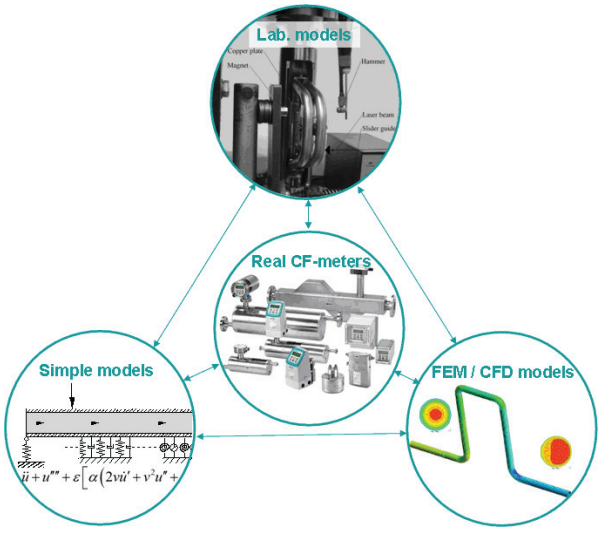
Solid Mechanics

Research activities

Coriolis flowmetering: Effects of imperfections on accuracy and precision
Coriolis flowmeters measure mass flow only indirectly: Fluid is directed through vibrating pipes, causing weak Coriolis forces, which create traveling waves, whose phase-shift is measurable and ideally proportional to mass flow. In reality non-idealities can influence measured phase shift in a way indistinguishable from mass flow, causing incorrect metering.

With Siemens Flow Instruments we develop generic mathematical models of the influence of non-idealities like asymmetry, nonlinearity, and non-uniformity in pipes, flow, drives and sensors.

In 2009 several of these model predictions have been validated against laboratory experiments with an industrial flowmeter.

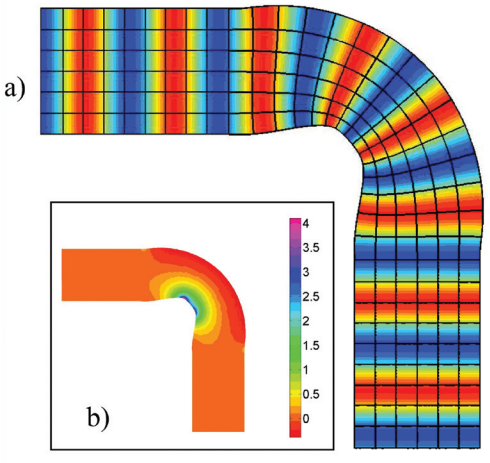


Coriolis flowmeter analysis.

Extreme non-linear elasticity and transformation optics
Transformation optics is a powerful concept for designing novel optical components such as high transmission waveguides and cloaking devices.

It turns out that an ideal transformation for TM (E_z) polarized light corresponds to the mechanical deformation of a compressible material with an extreme value of Poisson's ratio $\nu = -1$. Similarly, for TE (H_z) polarized light the deformation of an incompressible material with $\nu = ½$ is ideal.

Since computational mechanics is a mature field the discovery of this simple analogy opens doors for an automated and broader application of transformation optics based on advanced material modelling tools.



Optical response for TM (E_z) polarized light in a wave guide (a), where the transformation is the minimizer of the elastic energy potential for a negative Poisson's ratio material. The relative difference between the permittivity and the background permittivity (b), which displays the non-uniformity of the all dielectric realization required for the low loss transmission.

Main research topics are the mechanics of materials, the strength and dynamics of structural components and systems, machine elements and mechatronics.

In materials mechanics the work includes basic development of material models for inelasticity and damage, size effects on material behavior, micromechanics, and applications to fracture mechanics and fatigue. The structural mechanics research covers vibration analysis and advanced design using optimization methods.

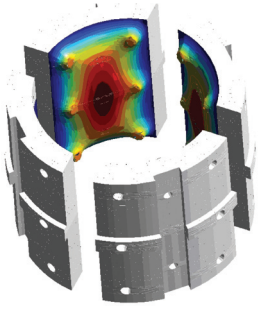
The design of multi physics problems, based on the Finite Element Method and Topology optimization, is also a major activity. The machine elements group works on tribology and active vibration damping through magnetic actuators.

Keyway optimization
With shape optimization and super elliptical shape parameterization, the fatigue life of a keyway can be greatly improved with up to a 50% reduction in the maximum stress level.

Optimization of energy absorbing materials
Through energy dissipation by fluid-structure interaction, this project optimizes materials for crash protection. The project is part of a collaboration with TU-Munich and makes use of topology optimization methods for optimal material design.

Controllable Elastohydrodynamic Lubrication
Due to the development of high performance rotating machinery, growing attention has been paid to the design of new active (mechatronic) devices able to actively control vibrations and improve its dynamic behavior.

The main original contribution of the research in the field of "controllable elastohydrodynamic lubrication" is the combination of elastohydrodynamics, fluid power, electronics and control techniques to achieve an even higher dynamic performance of rotors supported by tilting-pad bearings.



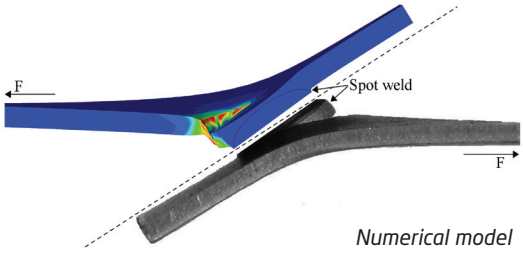
Pressure distribution over the 4 flexible pads of a tilting-pad journal bearing with 6 high pressure injection orifices - Fluid-structure finite element model.

Tilting-pad bearings under controllable elastohydro-dynamic lubrication regime belong to a special category of tribological devices where the bearing surface profile as well as the fluid film pressure are intentionally modified and/or adjusted via electronics in order to achieve such a high dynamic performance.

INNOJoint – damage modelling in welded joints
Welding and joining of materials are essential for modern industries in order to efficiently produce and assemble complex structure. In this PhD-project, commonly used techniques for testing Friction Stir Welded or Resistance Spot Welded joints have been studied numerically using advanced constitutive models that account for the complex mechanisms governing ductile failure by nucleation, growth and coalescence of micro-voids.

The influence of the non-homogeneous material properties in the weld region on failure during loading has been of specific interest in this work.

The model predictions from initial void nucleation to final fracture have shown good agreement with experimental observations.



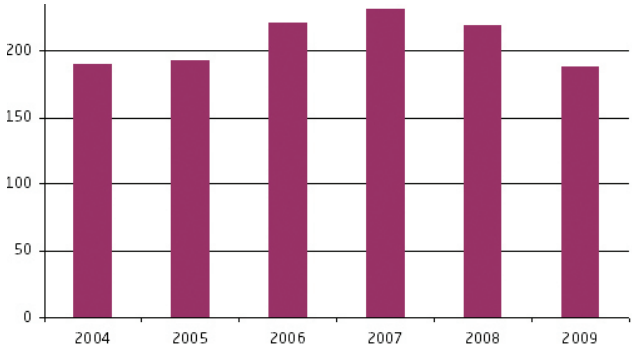
Numerical model

Stitching
Through-thickness reinforcement suppressing mode I delamination of laminates is investigated numerically. 2D and 3D models accounting for plasticity, contact and debonding are established and good agreement with experiments are found.

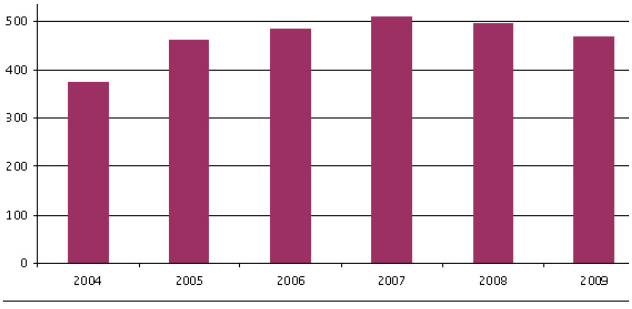
Key Figures

Education and Finances

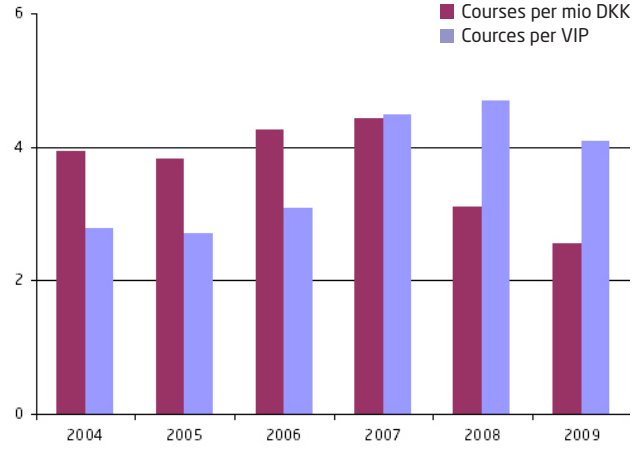
Number of courses



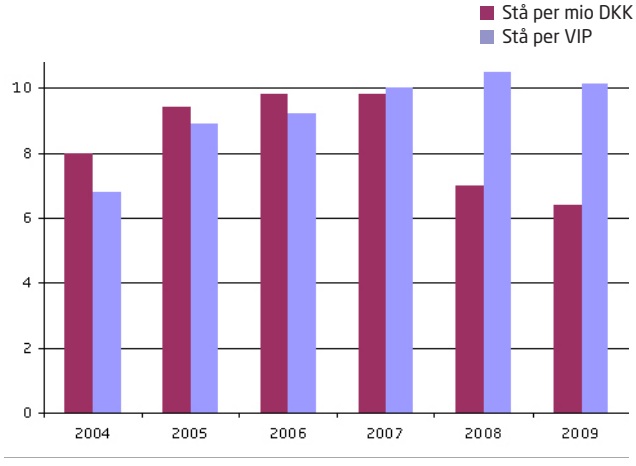
STÅ production



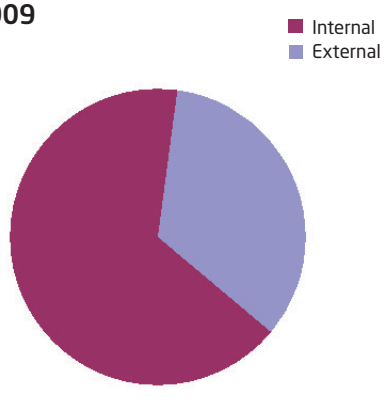
Number of courses per mio DKK & per VIP



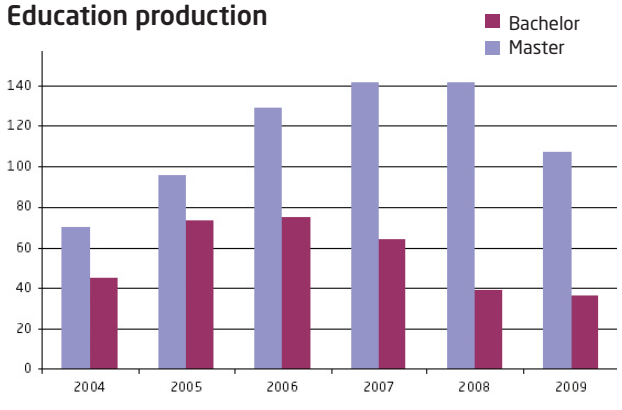
STÅ production per mio DKK & per VIP



Revenue 2009



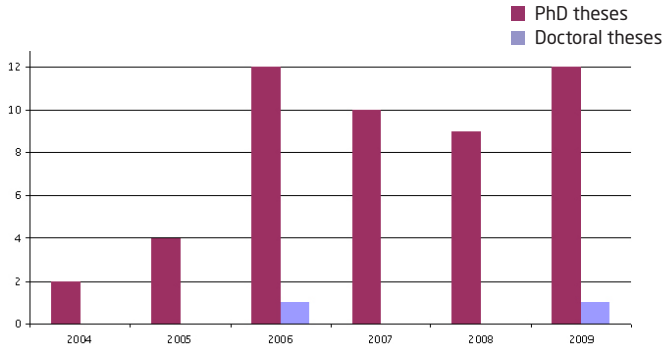
Education production



Key Figures

Research and Citations

Research production



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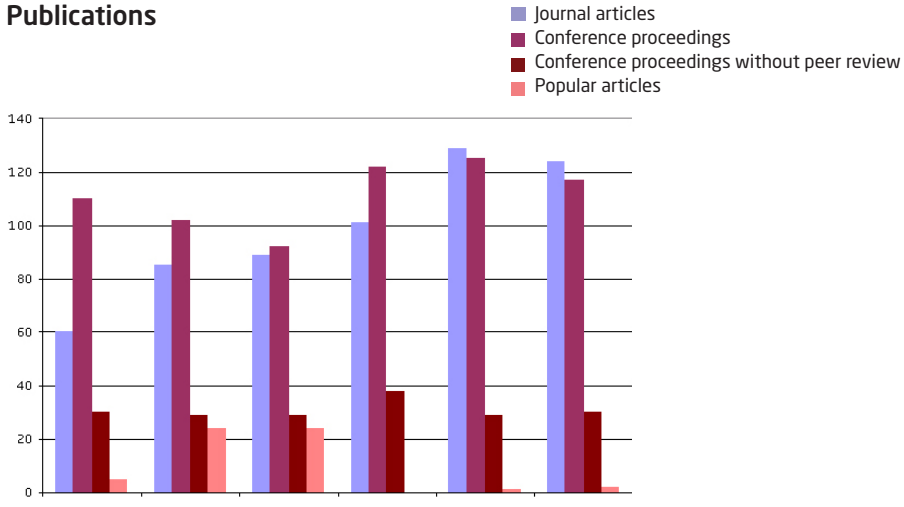
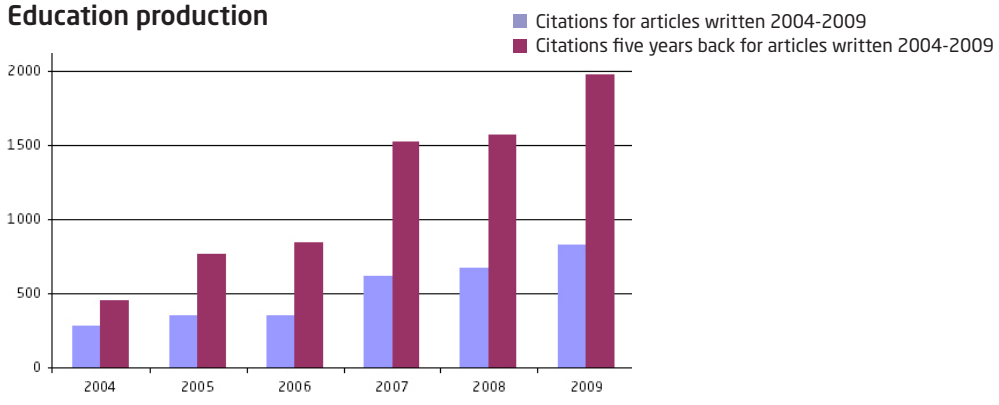
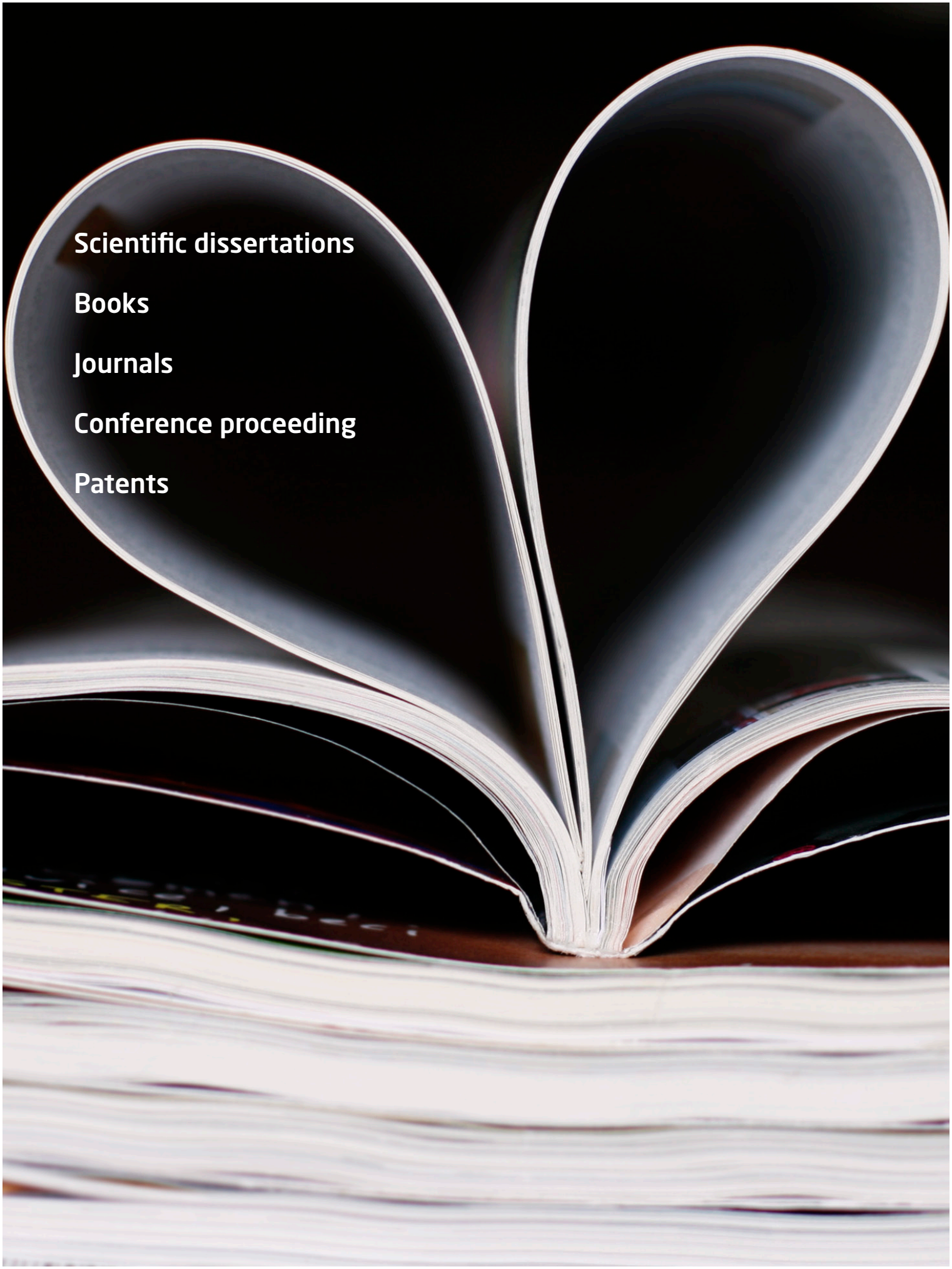


Education production

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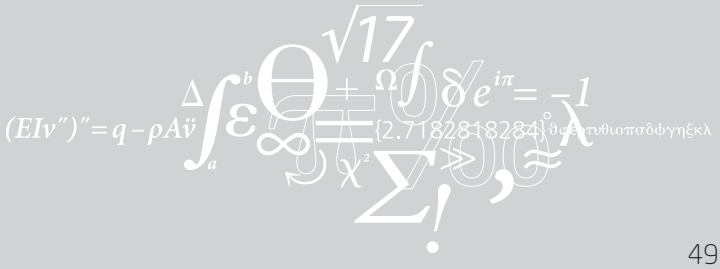

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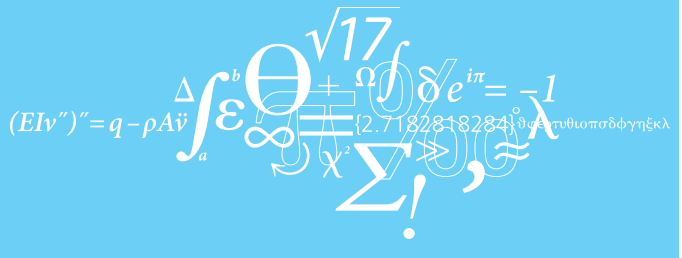

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