# Module Manual

Master of Science (M.Sc.)

# Materials Science and Engineering
# Dual study program

Cohort: Winter Term 2025

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# Program description

## Content

Materials - both classic as well as novel - are the basis and the driving force for products and product innovations. The most important material-based industries in Germany, including automotive and engineering, chemical, power engineering, electrical and electronics as well as metal manufacturing and processing, generate annual sales of nearly one trillion euros and employ around five million people.

Materials scientists are developing entirely new materials concepts - for example in current key fields such as energy storage and conversion or structural lightweight construction - or they are improving existing materials and adapting them to the constantly changing requirements of global competition. With their expertise on the complex implication of structure, composition, processing steps and load and environmental influences on the performance and behavior of materials in practical use, they are also a link between design and production.

Due to the importance of material behavior for the structural design and processing of products, the study of materials has a strong engineering component. At the same time, the understanding of material behavior is based on the most recent insights in basic natural science subjects. For example, although modern high-performance steels are produced on a 1000-tonne scale, the trend is increasing towards the design of such materials and their processing steps based on model calculations based on quantum-physical principles covering the entire scale from atom to component.

Novel composite and hybrid materials that combine high strength and low weight with functional properties such as actuators or sensors are using current research results from the nanoscience. The development of biomaterials, which are increasingly important in health care, requires insights from medicine in addition to materials physical and chemical approaches. The broad interdisciplinary approach of materials science makes them a bridging discipline between the engineering and natural sciences.

The master’s program Materials Science (M.Sc.) - Multiscale Material Systems is addressed to bachelor graduates of engineering as well as physics or chemistry. With its baseline-oriented curriculum, taking into account both natural science and engineering aspects, the program provides an understanding of the fabrication, design, properties, and design principles of materials, from atomic structures and processes to component behavior.

The focus of the first year of study are the core topics: physics and chemistry of materials, methods in experiment, theory and cross-scale modeling, mechanical properties ranging from molecules to idealized monocrystalline states to real material, phase transitions and microstructure design as well as properties of functional materials. Specialization areas open up the fields of nano- and hybrid materials, technical materials, and material modeling. In the second year of study, participation in current research is the focus, with a study project on Modern Problems of Materials Science as well as the Master's Thesis.

In addition to the foundational curriculum taught at TUHH, seminars on developing personal skills are integrated into the dual study programme, in the context of transfer between theory and practice. These seminars correspond to the modern professional requirements expected of an engineer, as well as promoting the link between the two places of learning.

The intensive dual courses at TUHH integrating practical experience consist of an academic-oriented and a practice-oriented element, which are completed at two places of learning. The academic-oriented element comprises study at TUHH. The practice-oriented element is coordinated with the study programme in terms of content and time, and consists of practical modules and phases spent in an affiliate company during periods when there are no lectures.

## Career prospects

Examples of task areas of materials scientists are:

- Materials expertise in construction
- process development and support in the materials producing and processing industry
- material and process development in research and development departments
- failure analysis
- quality assurance
- patents
- scientific research at universities and state research institutions

Business sectors include:

- vehicle and aircraft construction
- mechanical engineering
- chemical industry
- energy management
- electrical and electronics industry
- metal smelting and processing
- medical engineering
- civil engineering

In addition, students acquire basic professional and personal skills as part of the dual study programme that enable them to enter professional practice at an early stage and to go on to further study. Students also gain practical work experience through the integrated practical modules. Graduates of the dual course have broad foundational knowledge, fundamental skills for academic work and relevant personal competences.

## Learning target

Knowledge

- Graduates have learned the basic principles and acquired the knowledge and skills in the field of materials science that qualifies them for professional practice in a national and international environment. Graduates are able to describe the underlying scientific principles of materials science as well as the central experimental and computational methods.
- They have an advanced knowledge in the following subject areas and can explain them:
    - metals, ceramics, polymers and their composites
    - the mutual interplay between materials behavior, microstructure, and processing
    - mechanical properties, functional properties, phase transitions and microstructure evolution
    - characterization techniques in materials science
    - modeling approaches in materials science.
- Graduates can apply their knowledge in the above-mentioned subject areas as well as their methodological skills to scientific as well as technical materials-related tasks.
- They can identify and link the relevant fundamental methods and insights in order to solve scientific as well as technical problems in the area of

materials science and specifically in subject areas of their specialization.

Graduates with the specialization **"Construction Materials"**

- can evaluate metals, ceramics, polymers and composite materials for specific tasks in a technology-oriented environment.
- can develop and supervise sequences of processing steps.
- can make decisions on material selection, industrial production, quality assurance and failure analysis.

Graduates with the specialization **"Modeling"**

- can identify the appropriate modeling approaches for different phenomena on different length and time scales, adapt them to the respective problem and use them specifically for problem solving.
- can select and implement appropriate modeling approaches for given materials problems in science and technology. They can assess the significance and reliability of modeling results in relation to the real world observations.

Graduates with the specialization **"Nano and Hybrid Materials"**

- are familiar with the phenomena and physical or physico-chemical principles that link the properties of nanoscale bodies or of materials with a nanoscale microstructure to the characteristic length scales and to the presence and properties of interfaces. In particular, they can explain the relationships mentioned.
- can implement this knowledge for setting up or for optimizing and for implementing materials design strategies that modify the material's behavior through the following approaches: tailoring nanoscale microstructure geometry; tailoring the interfacial behavior; combining hard and soft matter at the nanoscale into hybrid materials.

Social competence

- Graduates can work in teams and can organize their workflow in a problem-based approach, as a preparation for a research-oriented occupatio
- Graduates are able to present their results and insights in writing and orally and to match their presentation to its target audience
- Graduates should be able to critically and reflectively shape social processes, as well as play a decisive role in them with a sense of responsibility and a democratic sense of community.

Independence

- Graduates are able to develop branches of their subject in an effectively self-organized manner using scientific methodology.
- They are able to present their acquired knowledge in an independent manner using appropriate presentation techniques or to present it in a written document of appropriate scope.
- Graduates are able to identify additional information needs and develop a strategy to expand their knowledge independently.

By continually switching places of learnings throughout the dual study programme, it is possible for theory and practice to be interlinked. Students reflect theoretically on their individual professional practical experience, and apply the results of their reflection to new forms of practice. They also test theoretical elements of the course in a practical setting, and use their findings as a stimulus for theoretical debate.

### Program structure

The curriculum of the master's program "Materials Science and Engineering" is structured as follows:

Core qualification: 1.-3. Semester, a total of 96 credit points. In the core qualification, the modules for the dual study program and "Operation & Management" are also anchored with six credit points each.

Specialization: The students choose one of the three topics listed below, with the respective specializations during the 1st-3rd. Semesters 24 credits are earned:

- Specialization construction materials
- Specialization modeling
- Specialization nano and hybrid materials

Master thesis in the 4th semester: 30 credit points

The structural model of the dual study programme follows a module-differentiating approach. Given the practice-oriented element, the curriculum of the dual study programme is different compared to a standard Bachelor's course. Five practical modules are completed at the dual students' partner company as part of corresponding practical terms during lecture-free periods.

# Core Qualification

## Module M0523: Business & Management

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|---|---|
| **Module Responsible** | Prof. Matthias Meyer |
| **Admission Requirements** | Successful completion of the modul "Foundations of Management" |
| **Recommended Previous Knowledge** | None |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | • Students are able to find their way around selected special areas of management within the scope of business management.<br>• Students are able to explain basic theories, categories, and models in selected special areas of business management.<br>• Students are able to interrelate technical and management knowledge. |
| *Skills* | • Students are able to apply basic methods in selected areas of business management.<br>• Students are able to explain and give reasons for decision proposals on practical issues in areas of business management. |
| **Personal Competence** | |
| *Social Competence* | • Students are able to communicate in small interdisciplinary groups and to jointly develop solutions for complex problems |
| *Autonomy* | • Students are capable of acquiring necessary knowledge independently by means of research and preparation of material. |
| **Workload in Hours** | Depends on choice of courses |
| **Credit points** | 6 |

| **Courses** |
|---|
| **Information regarding lectures and courses can be found in the corresponding module handbook published separately.** |

## Module M1756: Practical module 1 (dual study program, Master's degree)

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Practical term 1 (dual study program, Master's degree) (L2887) | | 0 | 10 |

| | |
|---|---|
| **Module Responsible** | Dr. Henning Haschke |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Successful completion of a compatible dual B.Sc. at TU Hamburg or comparable practical work experience and competences in the area of interlinking theory and practice<br>• Course D from the module on interlinking theory and practice as part of the dual Master's course |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Dual students ...<br>• ... combine their knowledge of facts, principles, theories and methods gained from previous study content with acquired practical knowledge - in particular their knowledge of practical professional procedures and approaches, in the current field of activity in engineering.<br>• ... have a critical understanding of the practical applications of their engineering subject. |
| *Skills* | Dual students ...<br>• ... apply technical theoretical knowledge to complex, interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action.<br>• ... implement the university's application recommendations with regard to their current tasks.<br>• ... develop solutions as well as procedures and approaches in their field of activity and area of responsibility. |
| **Personal Competence** | |
| *Social Competence* | Dual students ...<br>• ... work responsibly in project teams within their working area and proactively deal with problems within their team.<br>• ... represent complex engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders. |
| *Autonomy* | Dual students ...<br>• ... define goals for their own learning and working processes as engineers.<br>• ... reflect on learning and work processes in their area of responsibility.<br>• ... reflect on the relevance of subject modules specialisations and specialisation for work as an engineer, and also implement the university's application recommendations and the associated challenges to positively transfer knowledge between theory and practice. |
| **Workload in Hours** | Independent Study Time 300, Study Time in Lecture 0 |
| **Credit points** | 10 |
| **Course achievement** | None |
| **Examination** | Written elaboration |
| **Examination duration and scale** | Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase. |
| **Assignment for the Following Curricula** | Civil Engineering: Core Qualification: Compulsory<br>Bioprocess Engineering: Core Qualification: Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Compulsory<br>Computer Science: Core Qualification: Compulsory<br>Data Science: Core Qualification: Compulsory<br>Electrical Engineering and Information Technology: Core Qualification: Compulsory<br>Electrical Engineering: Core Qualification: Compulsory<br>Energy Systems: Core Qualification: Compulsory<br>Environmental Engineering: Core Qualification: Compulsory<br>Aircraft Systems Engineering: Core Qualification: Compulsory<br>Computer Science in Engineering: Core Qualification: Compulsory<br>Information and Communication Systems: Core Qualification: Compulsory<br>International Management and Engineering: Core Qualification: Compulsory<br>Logistics, Infrastructure and Mobility: Core Qualification: Compulsory<br>Aeronautics: Core Qualification: Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Compulsory<br>Materials Science and Engineering: Core Qualification: Compulsory<br>Mechanical Engineering and Management: Core Qualification: Compulsory<br>Mechatronics: Core Qualification: Compulsory<br>Biomedical Engineering: Core Qualification: Compulsory<br>Microelectronics and Microsystems: Core Qualification: Compulsory |

| | |
|---|---|
| | Product Development, Materials and Production: Core Qualification: Compulsory<br>Renewable Energies: Core Qualification: Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Compulsory<br>Theoretical Mechanical Engineering: Core Qualification: Compulsory<br>Process Engineering: Core Qualification: Compulsory<br>Water and Environmental Engineering: Core Qualification: Compulsory |

| **Course L2887: Practical term 1 (dual study program, Master's degree)** | |
|---|---|
| **Typ** | |
| **Hrs/wk** | 0 |
| **CP** | 10 |
| **Workload in Hours** | Independent Study Time 300, Study Time in Lecture 0 |
| **Lecturer** | Dr. Henning Haschke |
| **Language** | DE |
| **Cycle** | WiSe/SoSe |
| **Content** | **Company onboarding process**<br>• Assigning a professional field of activity as an engineer (B.Sc.) and associated fields of work<br>• Establishing responsibilities and authorisation of the dual student within the company as an engineer (B.Sc.)<br>• Working independently in a team and on selected projects - across departments and, if applicable, across companies<br>• Scheduling the current practical module with a clear correlation to work structures<br>• Scheduling the examination phase/subsequent study semester<br>**Operational knowledge and skills**<br>• Company-specific: Responsibility as an engineer (B.Sc.) in their own area of work, coordinating team and project work, dealing with complex contexts and unsolved problems, developing and implementing innovative solutions<br>• Subject specialisation (corresponding to the chosen course [M.Sc.]) in the field of activity<br>• Systemic skills<br>• Implementing the university’s application recommendations (theory-practice transfer) in corresponding work and task areas across the company<br>**Sharing/reflecting on learning**<br>• Creating an e-portfolio<br>• Importance of course contents (M.Sc.) when working as an engineer<br>• Importance of development and innovation when working as an engineer |
| **Literature** | • Studierendenhandbuch<br>• Betriebliche Dokumente<br>• Hochschulseitige Handlungsempfehlungen zum Theorie-Praxis-Transfer |

## Module M1943: Applied Computational Methods for Material Science

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Applied Computational Methods for Material Science (L1626) | Project-/problem-based Learning | 4 | 6 |

| | |
|---|---|
| **Module Responsible** | Prof. Norbert Huber |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Fundamentals of technical mechanics (statics, strength of materials, beam bending), fundamentals of mechanical properties of materials (elasticity, plasticity), materials science (tensile testing, hardness testing, bending strength), programming (Python) |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students are able to model a specimen/part using an FEM preprocessor, to mesh it and to apply boundary conditions and materials. They are able to establish 2D models (plain strain, axisymmetric) as well as 3D models and to solve these with ABAQUS. Further, they will learn how to implement contact, as e.g. needed for the simulation of nanoindentation or four point bending with rollers. With the help of Python the reading of the results and their processing will be automized. The students will be able to submit and analyze jobs in an automized way for building a data base. They can analyze such data bases with respect to underlying relationships using machine learning and test hypotheses in relation to uniqueness and completeness. |
| *Skills* | The students are able to address a given problem in a scientific approach by splitting it into subproblems and by gaining the required knowledge needed for solving each sub problem. They learn based on examples, how hypotheses are developed and how these can be verified or falsified using computer methods. In addition, the students learn how the results of the individual sub problems can be tested with regard to their correctness and how to discuss them scientificially, at one hand, and how the sum of all subresults are to be discussed in the context of the given problem and formulated hypotheses, on the other hand. A significant part of this work is the documentation in a written report, which is in style and structure comparable in all relevant elements to a scientific report. |
| **Personal Competence** | |
| *Social Competence* | As the module is based on Problem Based Learning, the students will be able to work in small groups. This includes to discuss the content of the problem, to brainstorm, to work out hypotheses, prioritize them and to agree on those hypotheses and subproblems which shall be worked out in an organized way. Due to this, a significant part of the module relies on communication skills, organizational skills and time management. Finally, the ability to split a problem into the right subproblems and to put to gether the results from the subproblems for getting the answer of the big picture is an asset for efficient and effective problem solving in general. |
| *Autonomy* | The acquisition of the necessary know-how and the solution of the subproblems is carried out individually. Due to this, the students are in the position to adopt new computer methods (here in particular Python programming, FE modeling, machine learning) and to expand those as far as necessary to solve the given task. Furthermore, the students learn to document their methods and results in a comprehensible manner and via the corrections to absorb feedback for continuously furthering the existing skills. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Subject theoretical and practical work |
| **Examination duration and scale** | In total 3 problems, duration 3-4 weeks each, completed by submission of a written report. Assessment group/individal performance 50/50. |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Core Qualification: Compulsory |

### Course L1626: Applied Computational Methods for Material Science

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|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 4 |
| **CP** | 6 |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Lecturer** | Prof. Norbert Huber |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | Finite Element Method (discretisation, solver, programming with Python, automatized control and analysis of parametric studies)<br><br>Examples of elastomechanics (tension, bending, four-point-bending, contact)<br><br>Material behaviour (elasticity, plasticity, small and finite deformations, nonlinearities)<br><br>Solution of inverse problems (machining of data, artificial neural networks, direct and inverse solutions, existence and uniqueness) |
| **Literature** | Alle Vorlesungsmaterialien und Beispiellösungen (Input-Dateien, Python Scirpte) werden auf Stud.IP zur Verfügung gestellt.<br><br>All lecture material and example solutions (input files, python scripts) will be made available in Stud.IP. |

## Module M1944: Materials Physics and Atomistic Materials Modeling

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Materials Physics (L1624) | Lecture | 2 | 2 |
| Quantum Mechanics and Atomistic Materials Modeling (L1672) | Lecture | 2 | 2 |
| Exercises in Materials Physics and Modeling (L2002) | Recitation Section (small) | 2 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Patrick Huber |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Advanced mathematics, physics and chemistry for students in engineering or natural sciences |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students are able to<br>- explain the fundamentals of condensed matter physics<br>- describe the fundamentals of the microscopic structure and mechanics, thermodynamics and optics of materials systems.<br>- to understand concept and realization of advanced methods in atomistic modeling as well as to estimate their potential and limitations. |
| *Skills* | After attending this lecture the students<br>• can perform calculations regarding the thermodynamics, mechanics, electrical and optical properties of condensed matter systems<br>• are able to transfer their knowledge to related technological and scientific fields, e.g. materials design problems.<br>• can select appropriate model descriptions for specific materials science problems and are able to further develop simple models. |
| **Personal Competence** | |
| *Social Competence* | The students are able to present solutions to specialists and to develop ideas further. |
| *Autonomy* | Students are able to assess their knowldege continuously on their own by exemplified practice.<br>The students are able to assess their own strengths and weaknesses and define tasks independently. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Core Qualification: Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

### Course L1624: Materials Physics

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Patrick Huber |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | |
| **Literature** | Für den **Elektromagnetismus:**<br>• Bergmann-Schäfer: „Lehrbuch der Experimentalphysik“, Band 2: „Elektromagnetismus“, de Gruyter<br>Für die **Atomphysik:**<br>• Haken, Wolf: „Atom- und Quantenphysik“, Springer<br>Für die **Materialphysik und Elastizität:**<br>• Hornbogen, Warlimont: „Metallkunde“, Springer |

| Course L1672: Quantum Mechanics and Atomistic Materials Modeling | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Robert Meißner |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | - Why atomistic materials modeling<br>- Newton's equations of motion and numerical approaches<br>- Ergodicity<br>- Atomic models<br>- Basics of quantum mechanics<br>- Atomic & molecular many-electron systems<br>- Hartree-Fock and Density-Functional Theory<br>- Monte-Carlo Methods<br>- Molecular Dynamics Simulations<br>- Phase Field Simulations |
| **Literature** | Begleitliteratur zur Vorlesung (sortiert nach Relevanz):<br>1. Daan Frenkel & Berend Smit „Understanding Molecular Simulations“<br>2. Mark E. Tuckerman „Statistical Mechanics: Theory and Molecular Simulations“<br>3. Andrew R. Leach „Molecular Modelling: Principles and Applications“<br>Zur Vorbereitung auf den quantenmechanischen Teil der Klausur empfiehlt sich folgende Literatur<br>1. Regine Freudenstein & Wilhelm Kulisch "Wiley Schnellkurs Quantenmechanik" |

| Course L2002: Exercises in Materials Physics and Modeling | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Robert Meißner, Prof. Patrick Huber |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | |
| **Literature** | - Daan Frenkel & Berend Smit: Understanding Molecular Simulation from Algorithms to Applications<br>- Rudolf Gross und Achim Marx: Festkörperphysik<br>- Neil Ashcroft and David Mermin: Solid State Physics |

## Module M1946: Phenomena and Methods in Materials Science

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Experimental Methods for the Characterization of Materials (L1580) | Lecture | 2 | 2 |
| Phase equilibria and transformations (L1579) | Lecture | 2 | 2 |
| Übung zu Phänomene und Methoden der Materialwissenschaft (L2991) | Recitation Section (large) | 2 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Jörg Weißmüller |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge in Materials Science, e.g. Werkstoffwissenschaft I/II |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students will be able to explain the properties of advanced materials along with their applications in technology, in particular metallic, ceramic, polymeric, semiconductor, modern composite materials (biomaterials) and nanomaterials. |
| *Skills* | The students will be able to select material configurations according to the technical needs and, if necessary, to design new materials considering architectural principles from the micro- to the macroscale. The students will also gain an overview on modern materials science, which enables them to select optimum materials combinations depending on the technical applications. |
| **Personal Competence** | |
| *Social Competence* | The students are able to present solutions to specialists and to develop ideas further. |
| *Autonomy* | The students are able to ...<br>• assess their own strengths and weaknesses.<br>• gather new necessary expertise by their own. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | International Management and Engineering: Specialisation II. Product Development and Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Product Development: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Materials: Compulsory<br>Materials Science and Engineering: Core Qualification: Compulsory<br>Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Production: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Materials: Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

### Course L1580: Experimental Methods for the Characterization of Materials

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|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Shan Shi |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | • Structural characterization by photons, neutrons and electrons (in particular X-ray and neutron scattering, electron microscopy, tomography)<br>• Mechanical and thermodynamical characterization methods (indenter measurements, mechanical compression and tension tests, specific heat measurements)<br>• Characterization of optical, electrical and magnetic properties (spectroscopy, electrical conductivity and magnetometry) |
| **Literature** | William D. Callister und David G. Rethwisch, Materialwissenschaften und Werkstofftechnik, Wiley&Sons, Asia (2011).<br>William D. Callister, Materials Science and Technology, Wiley& Sons, Inc. (2007). |

| Course L1579: Phase equilibria and transformations | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Jörg Weißmüller |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | Fundamentals of statistical physics, formal structure of phenomenological thermodynamics, simple atomistic models and free-energy functions of solid solutions and compounds. Corrections due to nonlocal interaction (elasticity, gradient terms). Phase equilibria and alloy phase diagrams as consequence thereof. Simple atomistic considerations for interaction energies in metallic solid solutions. Diffusion in real systems. Kinetics of phase transformations for real-life boundary conditions. Partitioning, stability and morphology at solidification fronts. Order of phase transformations; glass transition. Phase transitions in nano- and microscale systems. |
| **Literature** | D.A. Porter, K.E. Easterling, “Phase transformations in metals and alloys”, New York, CRC Press, Taylor & Francis, 2009, 3. Auflage<br><br>Peter Haasen, „Physikalische Metallkunde“ , Springer 1994<br><br>Herbert B. Callen, “Thermodynamics and an introduction to thermostatistics”, New York, NY: Wiley, 1985, 2. Auflage.<br><br>Robert W. Cahn und Peter Haasen, "Physical Metallurgy", Elsevier 1996<br><br>H. Ibach, “Physics of Surfaces and Interfaces” 2006, Berlin: Springer. |

| Course L2991: Übung zu Phänomene und Methoden der Materialwissenschaft | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Shan Shi |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | Practice problems to practice and deepen the skills and content taught in the module.<br><br>Exercises explore mathematical details in greater depth with the aim of familiarizing students with equations/concepts and how to apply them in practice (e.g. defining thermodynamic potentials and relationships, calculating enthalpy and entropy of a solid solution, constructing phase diagrams, ...). |
| **Literature** | D.A. Porter, K.E. Easterling, “Phase transformations in metals and alloys”, New York, CRC Press, Taylor & Francis, 2009, 3. Auflage<br><br>Peter Haasen, „Physikalische Metallkunde“ , Springer 1994<br><br>Herbert B. Callen, “Thermodynamics and an introduction to thermostatistics”, New York, NY: Wiley, 1985, 2. Auflage.<br><br>Robert W. Cahn und Peter Haasen, "Physical Metallurgy", Elsevier 1996<br><br>H. Ibach, “Physics of Surfaces and Interfaces” 2006, Berlin: Springer.<br><br>William D. Callister und David G. Rethwisch, Materialwissenschaften und Werkstofftechnik, Wiley&Sons, Asia (2011).<br><br>William D. Callister, Materials Science and Technology, Wiley& Sons, Inc. (2007). |

## Module M1759: Linking theory and practice (dual study program, Master's degree)

| | |
|---|---|
| **Module Responsible** | Dr. Henning Haschke |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Successful completion of practical modules as part of the dual Bachelor's course<br>• Module "interlinking theory and practice as part of the dual Master's course" |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Dual students ...<br><br>... can describe and classify selected classic and current theories, concepts and methods<br><br>• related to project management and<br>• change and transformation management<br><br>... and apply them to specific situations, processes and plans in a personal, professional context. |
| *Skills* | Dual students ...<br><br>• ... anticipate typical difficulties, positive and negative effects, as well as success and failure factors in the engineering sector, evaluate them and consider promising strategies and courses of action.<br>• ... develop specialised technical and conceptual skills to solve complex tasks and problems in their professional field of activity/work. |
| **Personal Competence** | |
| *Social Competence* | Dual students ...<br><br>• ... can responsibly lead interdisciplinary teams within the framework of complex tasks and problems.<br>• ... engage in sector-specific and cross-sectoral discussions with experts, stakeholders and staff, representing their approaches, points of view and work results. |
| *Autonomy* | Dual students ...<br><br>• ... define, reflect and evaluate goals and measures for complex application-oriented projects and change processes.<br>• ... shape their professional area of responsibility independently and sustainably.<br>• ... take responsibility for their actions and for the results of their work. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written elaboration |
| **Examination duration and scale** | Studienbegleitende und semesterübergreifende Dokumentation: Die Leistungspunkte für das Modul werden durch die Anfertigung eines digitalen Lern- und Entwicklungsberichtes (E-Portfolio) erworben. Dabei handelt es sich um eine fortlaufende Dokumentation und Reflexion der Lernerfahrungen und der Kompetenzentwicklung im Bereich der Personalen Kompetenz. |

### Course L2890: Responsible Project Management in Engineering (for Dual Study Program)

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Dr. Henning Haschke, Heiko Sieben |
| **Language** | DE |
| **Cycle** | WiSe/SoSe |
| **Content** | • Theories and methods of project management<br>• Innovation management<br>• Agile project management<br>• Fundamentals of classic and agile methods<br>• Hybrid use of classic and agile methods<br>• Roles, perspectives and stakeholders throughout the project<br>• Initiating and coordinating complex engineering projects<br>• Principles of moderation, team management, team leadership, conflict management<br>• Communication structures: in-house, cross-company<br>• Public information policy<br>• Promoting commitment and empowerment<br>• Sharing experience with specialists and managers from the engineering sector<br>• Documenting and reflecting on learning experiences |
| **Literature** | Seminarapparat |

| Course L2891: Responsible Change and Transformation Management in Engineering (for Dual Study Program) | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Dr. Henning Haschke, Heiko Sieben |
| **Language** | DE |
| **Cycle** | WiSe/SoSe |
| **Content** | • Basic concepts, opportunities and limits of organisational change<br>• Models and methods of organisational design and development<br>• Strategic orientation and change, and their short-, medium- and long-term consequences for individuals, organisations and society as a whole<br>• Roles, perspectives and stakeholders in change processes<br>• Initiating and coordinating change measures in engineering<br>• Phase models of organisational change (Lewin, Kotter, etc.)<br>• Change-oriented information policy and dealing with resistance and uncertainty<br>• Promoting commitment and empowerment<br>• Successfully handling change and transformation: personally, as an employee, as a manager (personal, professional, organisational)<br>• Company-level and globally (systemic)<br>• Sharing experience with specialists and managers from the engineering sector<br>• Documenting and reflecting on learning experiences |
| **Literature** | Seminarapparat |

## Module M1757: Practical module 2 (dual study program, Master's degree)

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Practical term 2 (dual study program, Master's degree) (L2888) | | 0 | 10 |

| | |
|---|---|
| **Module Responsible** | Dr. Henning Haschke |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Successful completion of practical module 1 as part of the dual Master’s course<br>• course D from the module on interlinking theory and practice as part of the dual Master’s course |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Dual students ...<br>• ... combine their knowledge of facts, principles, theories and methods gained from previous study content with acquired practical knowledge - in particular their knowledge of practical professional procedures and approaches, in the current field of activity in engineering.<br>• ... have a critical understanding of the practical applications of their engineering subject. |
| *Skills* | Dual students ...<br>• ... apply technical theoretical knowledge to complex, interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action.<br>• ... implement the university’s application recommendations with regard to their current tasks.<br>• ... develop (new) solutions as well as procedures and approaches in their field of activity and area of responsibility - including in the case of frequently changing requirements (systemic skills). |
| **Personal Competence** | |
| *Social Competence* | Dual students ...<br>• ... work responsibly in cross-departmental and interdisciplinary project teams and proactively deal with problems within their team.<br>• ... represent complex engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders and develop these further together. |
| *Autonomy* | Dual students ...<br>• ... define goals for their own learning and working processes as engineers.<br>• ... reflect on learning and work processes in their area of responsibility.<br>• ... reflect on the relevance of subject modules specialisations and specialisation for work as an engineer, and also implement the university’s application recommendations and the associated challenges to positively transfer knowledge between theory and practice. |
| **Workload in Hours** | Independent Study Time 300, Study Time in Lecture 0 |
| **Credit points** | 10 |
| **Course achievement** | None |
| **Examination** | Written elaboration |
| **Examination duration and scale** | Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase. |
| **Assignment for the Following Curricula** | Civil Engineering: Core Qualification: Compulsory<br>Bioprocess Engineering: Core Qualification: Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Compulsory<br>Computer Science: Core Qualification: Compulsory<br>Data Science: Core Qualification: Compulsory<br>Electrical Engineering and Information Technology: Core Qualification: Compulsory<br>Electrical Engineering: Core Qualification: Compulsory<br>Energy Systems: Core Qualification: Compulsory<br>Environmental Engineering: Core Qualification: Compulsory<br>Aircraft Systems Engineering: Core Qualification: Compulsory<br>Computer Science in Engineering: Core Qualification: Compulsory<br>Information and Communication Systems: Core Qualification: Compulsory<br>International Management and Engineering: Core Qualification: Compulsory<br>Logistics, Infrastructure and Mobility: Core Qualification: Compulsory<br>Aeronautics: Core Qualification: Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Compulsory<br>Materials Science and Engineering: Core Qualification: Compulsory<br>Mechanical Engineering and Management: Core Qualification: Compulsory<br>Mechatronics: Core Qualification: Compulsory<br>Biomedical Engineering: Core Qualification: Compulsory |

| | |
|---|---|
| | Microelectronics and Microsystems: Core Qualification: Compulsory<br>Product Development, Materials and Production: Core Qualification: Compulsory<br>Renewable Energies: Core Qualification: Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Compulsory<br>Theoretical Mechanical Engineering: Core Qualification: Compulsory<br>Process Engineering: Core Qualification: Compulsory<br>Water and Environmental Engineering: Core Qualification: Compulsory |

| Course L2888: Practical term 2 (dual study program, Master's degree) | |
|---|---|
| **Typ** | |
| **Hrs/wk** | 0 |
| **CP** | 10 |
| **Workload in Hours** | Independent Study Time 300, Study Time in Lecture 0 |
| **Lecturer** | Dr. Henning Haschke |
| **Language** | DE |
| **Cycle** | WiSe/SoSe |
| **Content** | **Company onboarding process**<br>• Assigning a professional field of activity as an engineer (B.Sc.) and associated fields of work<br>• Establishing responsibilities and authorisation of the dual student within the company as an engineer (B.Sc.)<br>• Taking personal responsibility within a team and on selected projects - across departments and, if applicable, across companies<br>• Scheduling the current practical module with a clear correlation to work structures<br>• Scheduling the examination phase/subsequent study semester<br>**Operational knowledge and skills**<br>• Company-specific: Responsibility as an engineer (B.Sc.) in their own area of work, coordinating team and project work, dealing with complex contexts and unsolved problems, developing and implementing innovative solutions<br>• Subject specialisation (corresponding to the chosen course [M.Sc.]) in the field of activity<br>• Systemic skills<br>• Implementing the university's application recommendations (theory-practice transfer) in corresponding work and task areas across the company<br>**Sharing/reflecting on learning**<br>• Updating their e-portfolio<br>• Importance of course contents (M.Sc.) when working as an engineer<br>• Importance of development and innovation when working as an engineer |
| **Literature** | • Studierendenhandbuch<br>• Betriebliche Dokumente<br>• Hochschulseitige Anwendungsempfehlungen zum Theorie-Praxis-Transfer |

## Module M1947: Advanced Laboratory Materials Sciences

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Advanced Laboratory Materials Sciences (L1653) | Practical Course | 6 | 6 |

| | |
|---|---|
| **Module Responsible** | Prof. Jörg Weißmüller |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | knowledge of Materials Science fundamentals |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students know about selected experimental approaches in materials science. They are familiar with the sequence of representative experiments, typically including sample preparation and conditioning, characterization, data reduction, data analysis, error analysis and interpretation of the results. |
| *Skills* | The students are able to<br>• independently execute material science relevant experiments<br>• analyze experimental data<br>• critically assess the results and recognized implications in the relevant material science context |
| **Personal Competence** | |
| *Social Competence* | The students are able to<br>• perform experiments and protocol them through team work<br>• discuss scientific results in a format matched to an expert target audience |
| *Autonomy* | The students are able to<br>• gain access so the contents of the lab classes through on essentially self-organized approach<br>• independently write up a comprehensible protocol of the experimental procedures and results<br>• recognize the need for additional information and develop a strategy to independently advancing the knowledge and understanding |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written elaboration |
| **Examination duration and scale** | ca. 25 pages |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Core Qualification: Compulsory |

| Course L1653: Advanced Laboratory Materials Sciences | |
|---|---|
| **Typ** | Practical Course |
| **Hrs/wk** | 6 |
| **CP** | 6 |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Lecturer** | Prof. Jörg Weißmüller, Dr. Martin Ritter, Prof. Alexander Schlaich, Prof. Bodo Fiedler, Prof. Gerold Schneider, Prof. Kaline Pagnan Furlan, Prof. Patrick Huber |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | **Lab 1: Actuators for modern fuel injection systems - synthesis and properties of a model lead-free actuator**<br><br>Experimental work packages: Characterization of the size distribution of the starting powder and processing into a green body by cold isostatic pressing; characterization of crystallography and phase by X-ray diffraction. Characterization of permittivity and actuation potential-strain isotherms; measurement of density and grain size; measurement of fracture toughness via indentation techniques.<br><br>**Lab 2: Effects of damage in fiber composites on their residual strength.**<br>Experimental work packages: Fabrication of sample plates using prepreg/autoclave method; damage insertion using drop weight, analysis of impact damage using ultrasound; testing of residual strength of sample plates in compression test.<br><br>**Lab 3: Actuation with nanoporous metals**<br>Experimental work packages: metallurgical production of the starting alloy by melting in an electric arc furnace; transformation into a nanoporous body by electrochemical dealloying; electrochemical characterization, in particular with respect to specific surface area and structure size; characterization of electrochemical actuation by in-situ dilatometry in an electrochemical environment using the mechanisms of electrocapillarity<br><br>**Lab 4: Fluid transport through nanoporous membranes.**<br>Experimental work packages: Adaptation of a laser interferometer to the experiment; adjustment of the interferometer; documentation of the optical signature during capillary rise of water in a nanoporous silicon membrane.<br><br>**Lab 5: Micro- and nanostructure analysis using electron microscopy**<br><br>Experimental work packages: Slice-and-View tomography using Focused Ion Beam and 3D reconstruction; Compositional and phase analysis using scanning electron microscopy; nanoscale and crystal structure investigation using transmission electron microscopy<br><br>**Lab 6: Modeling atomistic interactions using machine learning**<br><br>Quantum chemical calculations of model systems using density functional theory; training an artificial neural network on interatomic interaction potentials; molecular dynamics simulation of the model systems using the learned interactions; structural analysis and comparison with experimental data. |
| **Literature** | • Aktuelle Übersichtsartikel aus Fachzeitschriften<br>• Current review articles from scientific journals |

## Module M1948: Mechanical Properties

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Mechanical Behaviour of Brittle Materials (L1661) | Lecture | 2 | 2 |
| Dislocation Theory of Plasticity (L1662) | Lecture | 2 | 2 |
| Exercise on mechanical properties (HÜ) (L3352) | Recitation Section (large) | 2 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Shan Shi |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics in Materials Science I/II |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain basic principles of crystallography, statics (free body diagrams, tractions) and thermodynamics (energy minimization, energy barriers, entropy) |
| *Skills* | Students are capable of using standardized calculation methods: tensor calculations, derivatives, integrals, tensor transformations |
| **Personal Competence** | |
| *Social Competence* | Students can provide appropriate feedback and handle feedback on their own performance constructively. |
| *Autonomy* | Students are able to<br>- assess their own strengths and weaknesses<br>- assess their own state of learning in specific terms and to define further work steps on this basis guided by teachers.<br>- work independently based on lectures and notes to solve problems, and to ask for help or clarifications when needed |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 180 min |
| **Assignment for the Following Curricula** | Mechanical Engineering - Product Development and Production: Specialisation Product Development: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Materials: Compulsory<br>Materials Science and Engineering: Core Qualification: Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Production: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Materials: Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

| Course L1661: Mechanical Behaviour of Brittle Materials | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Dr. Tim Fischer |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | **Theoretical Strength**<br>Of a perfect crystalline material, theoretical critical shear stress<br><br>**Real strength of brittle materials**<br>Energy release reate, stress intensity factor, fracture criterion<br><br>**Scattering of strength of brittle materials**<br>Defect distribution, strength distribution, Weibull distribution<br><br>**Heterogeneous materials I**<br>Internal stresses, micro cracks, weight function,<br><br>**Heterogeneous materials II**<br>Toughening mechanisms: crack bridging, fibres<br><br>**Heterogeneous materials III**<br>Toughening mechanisms. Process zone<br><br>**Testing methods to determine the fracture toughness of brittle materials**<br><br>**R-curve, stable/unstable crack growth, fractography**<br><br>**Thermal shock**<br><br>**Subcritical crack growth)**<br>v-K-curve, life time prediction<br><br>**Kriechen**<br><br>**Mechanical properties of biological materials**<br><br>**Examples of use for a mechanically reliable design of ceramic components** |
| **Literature** | D R H Jones, Michael F. Ashby, Engineering Materials 1, An Introduction to Properties, Applications and Design, Elesevier<br><br>D.J. Green, An introduction to the mechanical properties of ceramics”, Cambridge University Press, 1998<br><br>B.R. Lawn, Fracture of Brittle Solids“, Cambridge University Press, 1993<br><br>D. Munz, T. Fett, Ceramics, Springer, 2001<br><br>D.W. Richerson, Modern Ceramic Engineering, Marcel Decker, New York, 1992 |

| Course L1662: Dislocation Theory of Plasticity | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Shan Shi |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | This class will cover the principles of dislocation theory from a physical metallurgy perspective, providing a fundamental understanding of the relations between the strength and of crystalline solids and distributions of defects.<br><br>We will review the concept of dislocations, defining terminology used, and providing an overview of important concepts (e.g. linear elasticity, stress-strain relations, and stress transformations) for theory development. We will develop the theory of dislocation plasticity through derived stress-strain fields, associated self-energies, and the induced forces on dislocations due to internal and externally applied stresses. Dislocation structure will be discussed, including core models, stacking faults, and dislocation arrays (including grain boundary descriptions). Mechanisms of dislocation multiplication and strengthening will be covered along with general principles of creep and strain rate sensitivity. Final topics will include non-FCC dislocations, emphasizing the differences in structure and corresponding implications on dislocation mobility and macroscopic mechanical behavior; and dislocations in finite volumes. |
| **Literature** | Vorlesungsskript<br><br>Aktuelle Publikationen<br><br>Bücher:<br><br>Introduction to Dislocations, by D. Hull and D.J. Bacon<br><br>Theory of Dislocations, by J.P.  Hirth and J. Lothe<br><br>Physical Metallurgy, by Peter Hassen |

| Course L3352: Exercise on mechanical properties (HÜ) | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Shan Shi |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | |
| **Literature** | |

## Module M1949: Multiphase Materials

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Lecture: Multiscale Materials (L1659) | Lecture | 3 | 3 |
| Polymer Composites (L1891) | Lecture | 3 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Robert Meißner |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge in basics of polymers, physics and mechanics/micromechanics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can<br>- explain the complex relationships of the mechanics of composite materials, the failure mechanisms and physical properties.<br>- assess the interactions of microstructure and properties of the matrix and reinforcing materials.<br>- explain e.g. different fiber types, including relative contexts (e.g. sustainability, environmental protection).<br>They know different methods of modeling multiphase materials and can apply them. |
| *Skills* | Students are capable of<br>- using standardized methods of calculation and modeling using the finite element method in a specified context to use discretization, solver, Programming with Python, Automated control and evaluation of parameter studies and examples to calculate of elastic mechanics like tensile, bending, four point bend, crack propagation, J -Integral, Cohesive zone models, Contact.<br>- determining the material properties (elasticity, plasticity, small and large deformations, modeling of multiphase materials).<br>- to calculate and evaluate the mechanical properties (modulus, strength) of different materials.<br>- Approximate sizing using the network theory of the structural elements implement and evaluate.<br>- selecting appropriate solutions for mechanical material problems: Solution of inverse problems (neural networks, optimization methods). |
| **Personal Competence** | |
| *Social Competence* | Students can<br>- arrive at funded work results in heterogenius groups and document them.<br>- provide appropriate feedback and handle feedback on their own performance constructively. |
| *Autonomy* | Students are able to,<br>- assess their own strengths and weaknesses<br>- assess their own state of learning in specific terms and to define further work steps on this basis<br>They are able to fill gaps in as well as extent their knowledge using the literature and other sources provided by the supervisor. Furthermore, they can meaningfully extend given problems and pragmatically solve them by means of corresponding solutions and concepts. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 3h written exam |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Core Qualification: Compulsory |

| Course L1659: Lecture: Multiscale Materials | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Prof. Alexander Schlaich, Prof. Robert Meißner |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | The behavior of liquids in the interior (“bulk”) differs fundamentally from the behavior at phase boundaries. By introducing confining, this can be explpoited in a variety of applications, ranging from modified phase behavior to tunable adsorption properties (transparent/adsorbing).<br><br>In this LV we start with the thermodynamic properties of liquids, in particular to describe phase transitions (gas/liquid, liquid/solid). Based on this, we introduce concepts such as the free energy of an interface to describe wetting properties. The concepts used are suitable for the description of liquids<br>both at the interface of industrially relevant materials (e.g. metals hydrophobically coated surfaces) as well as biological materials (lipids , principles of self-organization).<br><br>Based on the understanding of interfacial properties, we then investigate the confinement effects, i.e. thermodynamic properties of liquids in porous media.<br>In particular, we consider effects such as capillary compensation, pore size-dependent phase transitions and the transport behavior.<br>Finally, we adress the question of how wetting properties can be altered, e.g. through electrical switching, how such functional materials be designed and which properties multi-scale materials, i.e. porous media with well-defined pore size distributions show. |
| **Literature** | (will be updated during the lecture period) |

| Course L1891: Polymer Composites | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Prof. Robert Meißner |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | Manufacturing and Properties of CNTs and Graphen<br><br>Manufacturing and Properties of 3-dimensional Graphenstruktures<br><br>Polymer Composites with carbon nanoparticles |
| **Literature** | Aktuelle Veröffentlichungen |

## Module M1758: Practical module 3 (dual study program, Master's degree)

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Practical term 3 (dual study program, Master's degree) (L2889) | | 0 | 10 |

| | |
|---|---|
| **Module Responsible** | Dr. Henning Haschke |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | • Successful completion of practical module 2 as part of the dual Master's course<br>• course E from the module on interlinking theory and practice as part of the dual Master's course |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Dual students ...<br>• ... combine their comprehensive and specialised engineering knowledge acquired from previous study contents with the strategy-oriented practical knowledge gained from their current field of work and area of responsibility.<br>• ... have a critical understanding of the practical applications of their engineering subject, as well as related fields when implementing innovations. |
| *Skills* | Dual students ...<br>• ... apply specialised and conceptual skills to solve complex, sometimes interdisciplinary problems within the company, and evaluate the associated work processes and results, taking into account different possible courses of action.<br>• ... implement the university's application recommendations with regard to their current tasks.<br>• ... develop new solutions as well as procedures and approaches to implement operational projects and assignments - even when facing frequently changing requirements and unpredictable changes (systemic skills).<br>• ... can use academic methods to develop new ideas and procedures for operational problems and issues, and to assess these with regard to their usability. |
| **Personal Competence** | |
| *Social Competence* | Dual students ...<br>• ... work responsibly in cross-departmental and interdisciplinary project teams and proactively deal with problems within their team.<br>• ... can promote the professional development of others in a targeted manner.<br>• ... represent complex and interdisciplinary engineering viewpoints, facts, problems and solution approaches in discussions with internal and external stakeholders and develop these further together. |
| *Autonomy* | Dual students ...<br>• ... reflect on learning and work processes in their area of responsibility.<br>• ... define goals for new application-oriented tasks, projects and innovation plans while reflecting on potential effects on the company and the public.<br>• ... reflect on the relevance of areas of specialisation and research for work as an engineer, and also implement the university's application recommendations and the associated challenges to positively transfer knowledge between theory and practice. |
| **Workload in Hours** | Independent Study Time 300, Study Time in Lecture 0 |
| **Credit points** | 10 |
| **Course achievement** | None |
| **Examination** | Written elaboration |
| **Examination duration and scale** | Documentation accompanying studies and across semesters: Module credit points are earned by completing a digital learning and development report (e-portfolio). This documents and reflects individual learning experiences and skills development relating to interlinking theory and practice, as well as professional practice. In addition, the partner company provides proof to the dual@TUHH Coordination Office that the dual student has completed the practical phase. |
| **Assignment for the Following Curricula** | Civil Engineering: Core Qualification: Compulsory<br>Bioprocess Engineering: Core Qualification: Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Compulsory<br>Computer Science: Core Qualification: Compulsory<br>Data Science: Core Qualification: Compulsory<br>Electrical Engineering and Information Technology: Core Qualification: Compulsory<br>Electrical Engineering: Core Qualification: Compulsory<br>Energy Systems: Core Qualification: Compulsory<br>Environmental Engineering: Core Qualification: Compulsory<br>Aircraft Systems Engineering: Core Qualification: Compulsory<br>Computer Science in Engineering: Core Qualification: Compulsory<br>Information and Communication Systems: Core Qualification: Compulsory<br>International Management and Engineering: Core Qualification: Compulsory<br>Logistics, Infrastructure and Mobility: Core Qualification: Compulsory |

| | |
|---|---|
| | Aeronautics: Core Qualification: Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Compulsory<br>Materials Science and Engineering: Core Qualification: Compulsory<br>Materials Science: Core Qualification: Compulsory<br>Mechanical Engineering and Management: Core Qualification: Compulsory<br>Mechatronics: Core Qualification: Compulsory<br>Biomedical Engineering: Core Qualification: Compulsory<br>Microelectronics and Microsystems: Core Qualification: Compulsory<br>Product Development, Materials and Production: Core Qualification: Compulsory<br>Renewable Energies: Core Qualification: Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Compulsory<br>Theoretical Mechanical Engineering: Core Qualification: Compulsory<br>Process Engineering: Core Qualification: Compulsory<br>Water and Environmental Engineering: Core Qualification: Compulsory |

| **Course L2889: Practical term 3 (dual study program, Master's degree)** | |
|---|---|
| **Typ** | |
| **Hrs/wk** | 0 |
| **CP** | 10 |
| **Workload in Hours** | Independent Study Time 300, Study Time in Lecture 0 |
| **Lecturer** | Dr. Henning Haschke |
| **Language** | DE |
| **Cycle** | WiSe/SoSe |
| **Content** | **Company onboarding process**<br>• Assigning a future professional field of activity as an engineer (M.Sc.) and associated fields of work<br>• Extending responsibilities and authorisation of the dual student within the company up to the intended first assignment after completing their studies<br>• Working responsibly in a team; project responsibility within own area - as well as across divisions and companies if necessary<br>• Scheduling the final practical module with a clear correlation to work structures<br>• Internal agreement on a potential topic or innovation project for the Master's dissertation<br>• Planning the Master's dissertation within the company in cooperation with TU Hamburg<br>• Scheduling the examination phase/subsequent study semester<br>**Operational knowledge and skills**<br>• Company-specific: dealing with change, project and team development, responsibility as an engineer in their future field of work (M.Sc.), dealing with complex contexts, frequent and unpredictable changes, developing and implementing innovative solutions<br>• Specialising in one field of work (final dissertation)<br>• Systemic skills<br>• Implementing the university's application recommendations (theory-practice transfer) in corresponding work and task areas across the company<br>**Sharing/reflecting on learning**<br>• E-portfolio<br>• Relevance of study content and personal specialisation when working as an engineer<br>• Relevance of research and innovation when working as an engineer |
| **Literature** | • Studierendenhandbuch<br>• betriebliche Dokumente<br>• Hochschulseitige Anwendungsempfehlungen zum Theorie-Praxis-Transfer |

## Module M1950: Advanced Functional Materials

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Advanced Functional Materials (L1625) | Seminar | 2 | 6 |

| | |
|---|---|
| **Module Responsible** | Prof. Patrick Huber |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge in Materials Science, e.g. Materials Science I/II |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students will be able to explain the properties of advanced materials along with their applications in technology, in particular metallic, ceramic, polymeric, semiconductor, modern composite materials (biomaterials) and nanomaterials. |
| *Skills* | The students will be able to select material configurations according to the technical needs and, if necessary, to design new materials considering architectural principles from the micro- to the macroscale. The students will also gain an overview on modern materials science, which enables them to select optimum materials combinations depending on the technical applications. |
| **Personal Competence** | |
| *Social Competence* | The students are able to present solutions to specialists and to develop ideas further. |
| *Autonomy* | The students are able to ...<br>• assess their own strengths and weaknesses.<br>• gather new necessary expertise by their own. |
| **Workload in Hours** | Independent Study Time 152, Study Time in Lecture 28 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Presentation |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Core Qualification: Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

### Course L1625: Advanced Functional Materials

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 6 |
| **Workload in Hours** | Independent Study Time 152, Study Time in Lecture 28 |
| **Lecturer** | Prof. Patrick Huber, Prof. Bodo Fiedler, Prof. Gerold Schneider, Prof. Jörg Weißmüller, Prof. Kaline Pagnan Furlan, Prof. Robert Meißner |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | 1. Porous Solids - Preparation, Characterization and Functionalities<br>2. Fluidics with nanoporous membranes<br>3. Thermoplastic elastomers<br>4. Optimization of polymer properties by nanoparticles<br>5. Fiber composites in automotive<br>6. Modeling of materials based on quantum mechanics<br>7. Biomaterials |
| **Literature** | Aktuelle Publikationen aus der Fachliteratur werden während der Veranstaltung bekanntgegeben. |

## Module M1951: Study work on Modern Issues in the Materials Sciences

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |

| | |
|---|---|
| **Module Responsible** | Prof. Jörg Weißmüller |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | knowledge of Materials Science fundamentals |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | In the field of their Research Project, the students can provide examples concerning the state-of-the-art in research, development, or application. They can critically discuss the relevant issues in the context of current problems and frameworks in science and society.<br><br>In the context of the Research Project, the students know the relevant fundamentals of materials science as well as methodological approach is suitable for the problem of the project. |
| *Skills* | The students have familiarized themselves with the approaches for independently acquiring the basic knowledge for solving the material science problem of their project. They can use the relevant resources as for example search engines and databases for scientific publications of patents.<br><br>The students are familiar with writing a report addressing a scientific audience, including the conventions for outline, citation and bibliography.<br><br>The can design and deliver on oral presentation of the project results.<br><br>The students can expose in detail and critically assess the scientific approaches that they chose for their scientific work on the project.<br><br>The students are able to independently perform scientific experiment, computations or simulation relevant for the project, perform the data analysis and provide a critical scientific discussion of their results. |
| **Personal Competence** | |
| *Social Competence* | Students are able to discuss scientific results with specific target groups, to document results in a written form and to present them orally. |
| *Autonomy* | The students have familiarized themselves with the challenges and approaches involved in independently solving a new research problems in the field of material science (see also Fachkompetenz/Fertigkeiten - English). |
| **Workload in Hours** | Independent Study Time 360, Study Time in Lecture 0 |
| **Credit points** | 12 |
| **Course achievement** | None |
| **Examination** | Study work |
| **Examination duration and scale** | according to FSPO |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Core Qualification: Compulsory |

# Specialization Engineering Materials

Students learn in the Engineering Materials specialization the evaluation of the different materials in the technology-oriented environment.

They gain knowledge about process planning as well as managing of projects or personnel. Students are able to evaluate and make decisions on materials, industrial production, quality assurance and failure analysis.

## Module M1342: Polymers

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Structure and Properties of Polymers (L0389) | Lecture | 2 | 3 |
| Processing and design with polymers (L1892) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Bodo Fiedler |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics: chemistry / physics / material science |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can use the knowledge of plastics and define the necessary testing and analysis.<br><br>They can explain the complex relationships structure-property relationship and<br><br>the interactions of chemical structure of the polymers, including to explain neighboring contexts (e.g. sustainability, environmental protection). |
| *Skills* | Students are capable of<br><br>- using standardized calculation methods in a given context to mechanical properties (modulus, strength) to calculate and evaluate the different materials.<br><br>- selecting appropriate solutions for mechanical recycling problems and sizing example stiffness, corrosion resistance. |
| **Personal Competence** | |
| *Social Competence* | Students can<br><br>- arrive at funded work results in heterogenius groups and document them.<br><br>- provide appropriate feedback and handle feedback on their own performance constructively. |
| *Autonomy* | Students are able to<br><br>- assess their own strengths and weaknesses.<br><br>- assess their own state of learning in specific terms and to define further work steps on this basis.<br><br>- assess possible consequences of their professional activity. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 180 min |
| **Assignment for the Following Curricula** | Mechanical Engineering - Product Development and Production: Specialisation Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Materials: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Product Development: Elective Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Production: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Materials: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

| Course L0389: Structure and Properties of Polymers | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Janina Mittelhaus, Prof. Bodo Fiedler |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | - Structure and properties of polymers<br><br>- Structure of macromolecules<br><br>Constitution, Configuration, Conformation, Bonds, Synthesis, Molecular weihght distribution<br><br>- Morphology<br><br>amorph, crystalline, blends<br><br>- Properties<br><br>Elasticity, plasticity, viscoelacity<br><br>- Thermal properties<br><br>- Electrical properties<br><br>- Theoretical modelling<br><br>- Applications |
| **Literature** | Ehrenstein: Polymer-Werkstoffe, Carl Hanser Verlag |

| Course L1892: Processing and design with polymers | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Janina Mittelhaus, Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | Manufacturing of Polymers: General Properties; Calendering; Extrusion; Injection Moulding; Thermoforming, Foaming; Joining<br><br>Designing with Polymers: Materials Selection; Structural Design; Dimensioning |
| **Literature** | Osswald, Menges: Materials Science of Polymers for Engineers, Hanser Verlag<br>Crawford: Plastics engineering, Pergamon Press<br>Michaeli: Einführung in die Kunststoffverarbeitung, Hanser Verlag<br><br>Konstruieren mit Kunststoffen, Gunter Erhard , Hanser Verlag |

## Module M1952: Fatigue of metallic structural materials and methods for extending service life

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Fatigue of metallic structural materials (L2355) | Lecture | 2 | 3 |
| Method for life extension (L2356) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Dr. Nikolai Kashaev |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge of materials engineering and materials mechanics. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students are able to understand the fatigue problem in metallic materials as well as structures and components with consideration of materials and manufacturing aspects across the board. |
| *Skills* | The students are able to describe fatigue behavior of components as well as to independently carry out strategies for an optimal design of components with regard to their fatigue behavior. |
| **Personal Competence** | |
| *Social Competence* | The students are able to discuss fatigue problems in metallic structural components and their solutions for optimal design of components in terms of their fatigue behavior with others. |
| *Autonomy* | The students are able to test their own understanding of complex fatigue problems in structural components and appropriate methods for life extension by solving relevant tasks or problems. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory |

| Course L2355: Fatigue of metallic structural materials | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Dr. Nikolai Kashaev |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | The module with two lectures aims to provide students with the basic knowledge of the fatigue behaviour of metallic structural materials. In this module together with material engineering aspects of damage development also mechanical engineering methods of structural integrity evaluation are considered. In the lecture "Fatigue of Metallic Structural Materials", students are taught knowledge of both experimental material and component testing with regard to fatigue and damage tolerance, as well as fracture mechanics approach for describing fatigue behaviour. The important aspects of the lecture "Methods for Extending the Service Life " are on the one hand consideration of the influence of residual stresses on fatigue behaviour and on the other hand the use of optimal fatigue design as well as surface modification methods for service life extension. The aim of the module is to enable the students to understand the fatigue problem in metallic materials as well as structures and components with consideration of the manufacturing aspects in a comprehensive way and to be able to carry out strategies for an optimal fatigue design independently.<br><br>Contents of the course "Fatigue of metallic structural materials":<br><br>1. Introduction. Basic aspect of fatigue behavior of structural metallic materials<br><br>2. Elements of fracture mechanics<br><br>3. Fatigue properties of metallic materials<br><br>4. Fatigue strength. Stress concentrations at notches<br><br>5. Fatigue strength. Variable amplitude loading<br><br>6. Fatigue crack propagation<br><br>7. Prediction of fatigue crack propagation. Variable amplitude loading<br><br>8. Prediction of fatigue crack propagation considering residual stresses<br><br>9. Low cycle fatigue<br><br>10. Fracture mechanics based prediction of fatigue behavior<br><br>11. Stress corrosion cracking. Corrosion fatigue<br><br>12. Fretting fatigue.<br><br>13. High temperature and low temperature fatigue.<br><br>14. Concepts for structural integrity assessment (fail-safe, safe-life, damage-tolerance, defect-tolerance)<br><br>15. Damage tolerance design of additively manufactured components |
| **Literature** | 1. Schijve J. Fatigue of Structures and Materials. 2nd ed. Delft: Springer; 2009.<br><br>2. McEvily A.J. Metal Failures. Mechanisms, Analysis, Prevention. 2nd ed. Hoboken: Wiley; 2013.<br><br>3. Eswara Prasad N, Wanhill RJH, eds. Aerospace Materials and Material Technologies. Volume 2: Aerospace Material Technologies. Singapore: Springer; 2017.<br><br>4. Xiong J.J., Shenoi R.A. Fatigue and Fracture Reliability Engineering. Springer, 2011.<br><br>5. Tavares SMO, de Castro PMST. An overview of fatigue in aircraft structures. Fatigue Fract Eng Mater Struct. 2017;40(10):1510-1529.<br><br>6. Sticchi M, Schnubel D, Kashaev N, Huber N. Review of residual stress modification techniques for extending the fatigue life of metallic aircraft components. Appl Mech Rev. 2015;67(1):010801.<br><br>7. Zerbst U, Bruno G, Buffiere JY, et al. Damage tolerant design of additively manufactured metallic components subjected to cyclic loading: State of the art and challenges. Progr Mater Sci. 2021;121:100786. |

| Course L2356: Method for life extension | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Dr. Nikolai Kashaev |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | The module with two lectures aims to provide students with the basic knowledge of the fatigue behaviour of metallic structural materials. In this module together with material engineering aspects of damage development also mechanical engineering methods of structural integrity evaluation are considered. In the lecture "Fatigue of Metallic Structural Materials", students are taught knowledge of both experimental material and component testing with regard to fatigue and damage tolerance, as well as fracture mechanics approach for describing fatigue behaviour. The important aspects of the lecture "Methods for Extending the Service Life " are on the one hand consideration of the influence of residual stresses on fatigue behaviour and on the other hand the use of optimal fatigue design as well as surface modification methods for service life extension. The aim of the module is to enable the students to understand the fatigue problem in metallic materials as well as structures and components with consideration of the manufacturing aspects in a comprehensive way and to be able to carry out strategies for an optimal fatigue design independently.<br><br>Contents of the course "Methods for extending the service life":<br><br>1. Degradation and failure of structural metallic materials<br><br>2. Failure mechanisms of metallic structural materials<br><br>3. Thermal and residual stresses<br><br>4. Residual stress analyzing techniques<br><br>5. Fundamental aspects of Fe-C alloys and their base processing technologies for fabrication of components<br><br>6. Fundamental aspects of light-weight metallic structural materials and their base processing technologies for fabrication of components<br><br>7. Surface engineering. Thermochemical heat treatment. Coatings<br><br>8. Surface engineering. Mechanical treatment techniques<br><br>9. Recommendations from materials engineering for the design of structural components<br><br>10. Manufacturing technologies and their influence on residual stress state and fatigue properties |
| **Literature** | 1. Schijve J. Fatigue of Structures and Materials. 2nd ed. Delft: Springer; 2009.<br><br>2. McEvily A.J. Metal Failures. Mechanisms, Analysis, Prevention. 2nd ed. Hoboken: Wiley; 2013.<br><br>3. Eswara Prasad N, Wanhill RJH, eds. Aerospace Materials and Material Technologies. Volume 2: Aerospace Material Technologies. Singapore: Springer; 2017.<br><br>4. Xiong J.J., Shenoi R.A. Fatigue and Fracture Reliability Engineering. Springer, 2011.<br><br>5. Tavares SMO, de Castro PMST. An overview of fatigue in aircraft structures. Fatigue Fract Eng Mater Struct. 2017;40(10):1510-1529.<br><br>6. Sticchi M, Schnubel D, Kashaev N, Huber N. Review of residual stress modification techniques for extending the fatigue life of metallic aircraft components. Appl Mech Rev. 2015;67(1):010801.<br><br>7. Zerbst U, Bruno G, Buffiere JY, et al. Damage tolerant design of additively manufactured metallic components subjected to cyclic loading: State of the art and challenges. Progr Mater Sci. 2021;121:100786. |

## Module M1344: Processing of Fibre-Polymer-Composites

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Processing of fibre-polymer-composites (L1895) | Lecture | 2 | 3 |
| From Molecule to Composites Part (L1516) | Project-/problem-based Learning | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Bodo Fiedler |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge in the basics of chemistry / physics / materials science |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able to give a summary of the technical details of the manufacturing processes composites and illustrate respective relationships. They are capable of describing and communicating relevant problems and questions using appropriate technical language. They can explain the typical process of solving practical problems and present related results. |
| *Skills* | Students can use the knowledge of fiber-reinforced composites (FRP) and its constituents (fiber / matrix) and define the necessary testing and analysis.<br><br>They can explain the complex structure-property relationship and<br><br>the interactions of chemical structure of the polymers, their processing with the different fiber types, including to explain neighboring contexts (e.g. sustainability, environmental protection). |
| **Personal Competence** | |
| *Social Competence* | Students are able to cooperate in small, mixed-subject groups in order to independently derive solutions to given problems in the context of civil engineering. They are able to effectively present and explain their results alone or in groups in front of a qualified audience. Students have the ability to develop alternative approaches to an engineering problem independently or in groups and discuss advantages as well as drawbacks. |
| *Autonomy* | Students are capable of independently solving mechanical engineering problems using provided literature. They are able to fill gaps in as well as extent their knowledge using the literature and other sources provided by the supervisor. Furthermore, they can meaningfully extend given problems and pragmatically solve them by means of corresponding solutions and concepts. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Aeronautics: Core Qualification: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Product Development: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Materials: Elective Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Production: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Materials: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

### Course L1895: Processing of fibre-polymer-composites

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | Manufacturing of Composites: Hand Lay-Up; Pre-Preg; GMT, BMC; SMC, RIM; Pultrusion; Filament Winding |
| **Literature** | Åström: Manufacturing of Polymer Composites, Chapman and Hall |

| Course L1516: From Molecule to Composites Part | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | Students get the task in the form of a customer request for the development and production of a MTB handlebar made of fiber composites. In the task technical and normative requirements (standards) are given, all other required information come from the lectures and tutorials, and the respective documents (electronically and in conversation).<br>The procedure is to specify in a milestone schedule and allows students to plan tasks and to work continuously. At project end, each group has a made handlebar with approved quality.<br>In each project meeting the design (discussion of the requirements and risks) are discussed. The calculations are analyzed, evaluated and established manufacturing methods are selected. Materials are selected bar will be produced. The quality and the mechanical properties are checked. At the end of the final report created (compilation of the results for the "customers").<br>After the test during the "customer / supplier conversation" there is a mutual feedback-talk ("lessons learned") in order to ensure the continuous improvement. |
| **Literature** | Åström: Manufacturing of Polymer Composites, Chapman and Hall |

## Module M1343: Structure and properties of fibre-polymer-composites

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Structure and properties of fibre-polymer-composites (L1894) | Lecture | 2 | 3 |
| Structure and properties of fibre-polymer-composites (L2614) | Project-/problem-based Learning | 2 | 2 |
| Structure and properties of fibre-polymer-composites (L2613) | Recitation Section (large) | 1 | 1 |

| | |
|---|---|
| **Module Responsible** | Prof. Bodo Fiedler |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics: chemistry / physics / materials science |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can use the knowledge of fiber-reinforced composites (FRP) and its constituents to play (fiber / matrix) and define the necessary testing and analysis.<br><br>They can explain the complex relationships structure-property relationship and<br><br>the interactions of chemical structure of the polymers, their processing with the different fiber types, including to explain neighboring contexts (e.g. sustainability, environmental protection). |
| *Skills* | Students are capable of<br><br>• using standardized calculation methods in a given context to mechanical properties (modulus, strength) to calculate and evaluate the different materials.<br>• approximate sizing using the network theory of the structural elements implement and evaluate.<br>• selecting appropriate solutions for mechanical recycling problems and sizing example stiffness, corrosion resistance. |
| **Personal Competence** | |
| *Social Competence* | Students can<br><br>• arrive at funded work results in heterogenius groups and document them.<br>• provide appropriate feedback and handle feedback on their own performance constructively. |
| *Autonomy* | Students are able to<br><br>- assess their own strengths and weaknesses.<br><br>- assess their own state of learning in specific terms and to define further work steps on this basis.<br><br>- assess possible consequences of their professional activity. |
| **Workload in Hours** | Independent Study Time 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Aircraft Systems Engineering: Core Qualification: Elective Compulsory<br>International Management and Engineering: Specialisation II. Product Development and Production: Elective Compulsory<br>Aeronautics: Core Qualification: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Product Development: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Specialisation Materials: Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Mechanical Engineering and Management: Core Qualification: Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Product Development: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Production: Elective Compulsory<br>Product Development, Materials and Production: Specialisation Materials: Compulsory<br>Renewable Energies: Specialisation Bioenergy Systems: Elective Compulsory<br>Renewable Energies: Specialisation Wind Energy Systems: Elective Compulsory<br>Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

| Course L1894: Structure and properties of fibre-polymer-composites | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | - Microstructure and properties of the matrix and reinforcing materials and their interaction<br>- Development of composite materials<br>- Mechanical and physical properties<br>- Mechanics of Composite Materials<br>- Laminate theory<br>- Test methods<br>- Non destructive testing<br>- Failure mechanisms<br>- Theoretical models for the prediction of properties<br>- Application |
| **Literature** | Hall, Clyne: Introduction to Composite materials, Cambridge University Press<br>Daniel, Ishai: Engineering Mechanics of Composites Materials, Oxford University Press<br>Mallick: Fibre-Reinforced Composites, Marcel Deckker, New York |

| Course L2614: Structure and properties of fibre-polymer-composites | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | The students receive the assignment in the form of a material design for test bodies made of fibre composites. Technical and normative requirements are listed in the assignment, all other required information comes from the lectures and exercises or the respective documents (electronically and in conversation).<br><br>The procedure is specified in a milestone plan and enables the students to plan subtasks and thus work continuously. At the end of the project, different test specimens were tested in tensile or bending tests.<br><br>In the individual project meetings, the conception (discussion of requirements and risks) is scrutinised. The calculations are analysed, the production methods are evaluated and determined. Materials are selected and the test specimens are manufactured according to standards. The quality and mechanical properties are checked and classified. At the end, a final report is prepared and the results are presented to all participants in the form of a presentation and discussed.<br><br>Translated with www.DeepL.com/Translator (free version) |
| **Literature** | Hall, Clyne: Introduction to Composite materials, Cambridge University Press<br>Daniel, Ishai: Engineering Mechanics of Composites Materials, Oxford University Press<br>Mallick: Fibre-Reinforced Composites, Marcel Deckker, New York |

| Course L2613: Structure and properties of fibre-polymer-composites | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 1 |
| **CP** | 1 |
| **Workload in Hours** | Independent Study Time 16, Study Time in Lecture 14 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | The contents of the lecture are repeated and deepened using practical examples.<br><br>Calculations are carried out together or individually, and the results are discussed critically. |
| **Literature** | Hall, Clyne: Introduction to Composite materials, Cambridge University Press<br>Daniel, Ishai: Engineering Mechanics of Composites Materials, Oxford University Press<br>Mallick: Fibre-Reinforced Composites, Marcel Deckker, New York |

## Module M1665: Design and dimensioning of fibre-reinforced plastic composites (FRP)

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Design with fibre-polymer-composites (L1893) | Lecture | 2 | 3 |
| Design with fibre-polymer-composites (L2616) | Project-/problem-based Learning | 2 | 2 |
| Design with fibre-polymer-composites (L2615) | Recitation Section (large) | 1 | 1 |

| | |
|---|---|
| **Module Responsible** | Prof. Bodo Fiedler |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics: chemistry / physics / materials science |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can use the knowledge of fiber-reinforced composites (FRP) and its constituents to play (fiber / matrix) and define the necessary testing and analysis.<br><br>They can explain the complex relationships structure-property relationship and<br><br>the interactions of chemical structure of the polymers, their processing with the different fiber types, including to explain neighboring contexts (e.g. sustainability, environmental protection). |
| *Skills* | Students are capable of<br><br>• using standardized calculation methods in a given context to mechanical properties (modulus, strength) to calculate and evaluate the different materials.<br>• approximate sizing using the network theory of the structural elements implement and evaluate.<br>• selecting appropriate solutions for mechanical recycling problems and sizing example stiffness, corrosion resistance. |
| **Personal Competence** | |
| *Social Competence* | Students can<br><br>• arrive at funded work results in heterogenius groups and document them.<br>• provide appropriate feedback and handle feedback on their own performance constructively. |
| *Autonomy* | Students are able to<br><br>- assess their own strengths and weaknesses.<br><br>- assess their own state of learning in specific terms and to define further work steps on this basis.<br><br>- assess possible consequences of their professional activity. |
| **Workload in Hours** | Independent Study Time 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Aeronautics: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Product Development and Production: Elective Compulsory |

### Course L1893: Design with fibre-polymer-composites

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | Designing with Composites: Laminate Theory; Failure Criteria; Design of Pipes and Shafts; Sandwich Structures; Notches; Joining Techniques; Compression Loading; Examples |
| **Literature** | Konstruieren mit Kunststoffen, Gunter Erhard , Hanser Verlag |

| Course L2616: Design with fibre-polymer-composites | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | The students receive the assignment in the form of a material design for test bodies made of fibre composites. Technical and normative requirements are listed in the assignment, all other required information comes from the lectures and exercises or the respective documents (electronically and in conversation).<br><br>The procedure is specified in a milestone plan and enables the students to plan subtasks and thus work continuously. At the end of the project, different test specimens were tested in tensile or bending tests.<br><br>In the individual project meetings, the conception (discussion of requirements and risks) is scrutinised. The calculations are analysed, the production methods are evaluated and determined. Materials are selected and the test specimens are manufactured according to standards. The quality and mechanical properties are checked and classified. At the end, a final report is prepared and the results are presented to all participants in the form of a presentation and discussed. |
| **Literature** | Konstruieren mit Kunststoffen, Gunter Erhard , Hanser Verlag |

| Course L2615: Design with fibre-polymer-composites | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 1 |
| **CP** | 1 |
| **Workload in Hours** | Independent Study Time 16, Study Time in Lecture 14 |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | The contents of the lecture are repeated and deepened using practical examples. Calculations are carried out together or individually, and the results are discussed critically. |
| **Literature** | Konstruieren mit Kunststoffen, Gunter Erhard , Hanser Verlag |

## Module M1796: Magnetic resonance in engineering

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Fundamentals of Magnetic Resonance (L2968) | Lecture | 3 | 3 |
| Magnetic Resonance in Engineering (L2969) | Project-/problem-based Learning | 3 | 3 |

| | |
|---|---|
| **Module Responsible** | Dr. Stefan Benders |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | No special previous knowledge is necessary. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | This module covers the fundamentals of nuclear magnetic resonance spectroscopy (NMR) and magnetic resonance imaging (MRI) and their applications in engineering disciplines. The module consists of a classical lecture complemented by a problem-based learning course that includes practical hands-on experience on magnetic resonance devices. The module will be held in English. |
| *Skills* | After the successful completion of the course the students shall:<br>1. Understand the physical principles and practical aspects of magnetic resonance in engineering.<br>2. Know how to safely operate NMR and MRI systems.<br>3. Know how to run standard experimental sequences and how to implement more advanced sequence protocols.<br>4. Have an overview of the current capabilities and limits of the MR technique |
| **Personal Competence** | |
| *Social Competence* | In the problem-based course Magnetic Resonance in Engineering, the students will obtain hands-on experience on how to operate NMR spectrometers and high-field and low-field MRI systems. The course will cover safety aspects, pulse sequence design, spectral image analysis, and image reconstruction. The students will work in small groups on practical tasks on different NMR and MRI systems located at the campus of TUHH. |
| *Autonomy* | Through the practical character of the PBL course, the student shall improve their communication skills. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Subject theoretical and practical work |
| **Examination duration and scale** | 120 Minutes |
| **Assignment for the Following Curricula** | Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Process Engineering: Specialisation Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory |

| Course L2968: Fundamentals of Magnetic Resonance | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Dr. Stefan Benders |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | This lecture covers the fundamentals magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (NMR). It focuses on the following topics:<br>1. The fundamentals of magnetic resonance: magnetism, magnetic fields, radiofrequency, spin, relaxation<br>2. Hardware for magnetic resonance: magnets (high-field and low-field), radiofrequency coil design, magnetic field gradients<br>3. NMR-Spectroscopy: chemical shift, J-Coupling, 2D NMR, solid-state, MAS<br>4. Relaxometry: single-sided NMR, contrasts,<br>5. Magnetic resonance imaging (MRI): gradients, coils, k-space, imaging sequences, ultrafast Imaging, parallel imaging, velocimetry, CEST<br>6. Hyperpolarization techniques: DNP, p-H2, optical pumping with Xe<br>7. Applications of magnetic resonance in chemical engineering<br>8. Applications of magnetic resonance in material science and engineering<br>9. Applications of magnetic resonance in biomedical engineering |
| **Literature** | Stapf, S., & Han, S. (2006). NMR imaging in chemical engineering. Weinheim: Wiley-VCH. ISBN: 978-3-527-60719-8<br><br>Blümich B., (2003) NMR imaging of materials. Oxford University Press, Online- ISBN: 9780191709524 , doi: https://doi.org/10.1093/acprof:oso/9780198526766.001.0001<br><br>Brown R. W., Cheng Y. N., Haacke E. M., Thompson M. R., Venkatesan R., (2014) Magnetic Resonance Imaging: Physical Principles and Sequence Design, Second Edition, John Wiley & Sons, Inc., doi: 10.1002/9781118633953<br><br>Haber-Pohlmeier, Sabina, Bernhard Blumich, and Luisa Ciobanu, (2022) Magnetic Resonance Microscopy: Instrumentation and Applications in Engineering, Life Science, and Energy Research. John Wiley & Sons |

| Course L2969: Magnetic Resonance in Engineering | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Dr. Stefan Benders |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | In this course, the theoretical basics of magnetic resonance spectroscopy and magnetic resonance tomography are supplemented with practical experiments on the respective devices. The practical handling and operation of the equipment will be learned. |
| **Literature** | Stapf, S., & Han, S. (2006). NMR imaging in chemical engineering. Weinheim: Wiley-VCH. ISBN: 978-3-527-60719-8<br><br>Blümich B., (2003) NMR imaging of materials. Oxford University Press, Online- ISBN: 9780191709524, doi: https://doi.org/10.1093/acprof:oso/9780198526766.001.0001<br><br>Brown R. W., Cheng Y. N., Haacke E. M., Thompson M. R., Venkatesan R., (2014) Magnetic Resonance Imaging: Physical Principles and Sequence Design, Second Edition, John Wiley & Sons, Inc., doi: 10.1002/9781118633953 |

## Module M1915: Materials Science Seminar

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Seminar (L1757) | Seminar | 2 | 3 |
| Seminar Composites (L1758) | Seminar | 2 | 3 |
| Seminar Advanced Ceramics (L1801) | Seminar | 2 | 3 |
| Seminar on interface-dominated materials (L1795) | Seminar | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Jörg Weißmüller |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Fundamental knowledge on nanomaterials, electrochemistry, interface science, mechanics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain the most important facts and relationships of a specific topic from the field of materials science. |
| *Skills* | Students are able to compile a specified topic from the field of materials science and to give a clear, structured and comprehensible presentation of the subject. They can comply with a given duration of the presentation. They can write in English a summary including illustrations that contains the most important results, relationships and explanations of the subject. |
| **Personal Competence** | |
| *Social Competence* | Students are able to adapt their presentation with respect to content, detailedness, and presentation style to the composition and previous knowledge of the audience. They can answer questions from the audience in a curt and precise manner. |
| *Autonomy* | Students are able to autonomously carry out a literature research concerning a given topic. They can independently evaluate the material. They can self-reliantly decide which parts of the material should be included in the presentation. |
| **Workload in Hours** | Depends on choice of courses |
| **Credit points** | 3 |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Modeling: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory |

### Course L1757: Seminar

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Jörg Weißmüller, Prof. Shan Shi |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | Current topics of materials research in the field of metallic nanomaterials. |
| **Literature** | Ausgehend von aktuellen Fachpublikationen erarbeiten die Studierenden unter Anleitung die wissenschaftlichen Grundlagen und stellen dazu die jeweils relevanten Arbeiten aus der Fachliteratur zusammen.<br><br>Based on current scientific publications, and under guidance, students work out the scientific fundamentals and compile the relevant works from the professional literature in each case. |

| Course L1758: Seminar Composites | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | Current topics in materials research in the field of polymers, their composites and nanomaterials. |
| **Literature** | Based on current scientific publications, and under guidance, students work out the scientific fundamentals and compile the relevant works from the professional literature in each case. |

| Course L1801: Seminar Advanced Ceramics | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Gerold Schneider, Prof. Kaline Pagnan Furlan |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | |
| **Literature** | |

| Course L1795: Seminar on interface-dominated materials | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Patrick Huber |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | |
| **Literature** | |

## Module M1345: Metallic and Hybrid Light-weight Materials

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Joining of Polymer-Metal Lightweight Structures (L0500) | Lecture | 2 | 2 |
| Joining of Polymer-Metal Lightweight Structures (L0501) | Practical Course | 1 | 1 |
| Metallic Light-weight Materials (L1660) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Marcus Rutner |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | |
| *Skills* | |
| **Personal Competence** | |
| *Social Competence* | |
| *Autonomy* | |
| **Workload in Hours** | Independent Study Time 110, Study Time in Lecture 70 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Oral exam |
| **Examination duration and scale** | 45 min |
| **Assignment for the Following Curricula** | Civil Engineering: Specialisation Structural Engineering: Elective Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

### Course L0500: Joining of Polymer-Metal Lightweight Structures

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Marcus Rutner |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | **Contents:**<br><br>The lecture and the related laboratory exercises intend to provide an insight on advanced joining technologies for polymer-metal lightweight structures used in engineering applications. A general understanding of the principles of the consolidated and new technologies and its main fields of applications is to be accomplished through theoretical and practical lectures.<br><br>**Theoretical Lectures:**<br><br>• Review of the relevant properties of Lightweight Alloys, Engineering Plastics and Composites in Joining Technology<br>• Introduction to Welding of Lightweight Alloys, Thermoplastics and Fiber Reinforced Plastics<br>• Mechanical Fastening of Polymer-Metal Hybrid Structures<br>• Adhesive Bonding of Polymer-Metal Hybrid Structures<br>• Fusion and Solid State Joining Processes of Polymer-Metal Hybrid Structures<br>• Hybrid Joining Methods and Direct Assembly of Polymer-Metal Hybrid Structures<br><br>**Laboratory Exercises:**<br><br>• Joining Processes: Introduction to state-of-the-art joining technologies<br>• Introduction to metallographic specimen preparation, optical microscopy and mechanical testing of polymer-metal joints<br><br>**Course Outcomes:**<br><br>After successful completion of this unit, students should be able to understand the principles of welding and joining of polymer-metal lightweight structures as well as their application fields. |
| **Literature** | • S. T. Amancio-Filho, L.-A. Blaga, Joining of Polymer-Metal Hybrid Structures, Wiley, 2018<br>• J.F. Shackelford, Introduction to materials science for engineers, Prentice-Hall International<br>• J. Rotheiser, Joining of Plastics, Handbook for designers and engineers, Hanser Publishers<br>• D.A. Grewell, A. Benatar, J.B. Park, Plastics and Composites Welding Handbook<br>• D. Lohwasser, Z. Chen, Friction Stir Welding, From basics to applications, Woodhead Publishing Limited<br>• J. Friedrich, Metal-Polymer Systems: Interface Design and Chemical Bonding, Wiley, 2017 |

| Course L0501: Joining of Polymer-Metal Lightweight Structures | |
|---|---|
| **Typ** | Practical Course |
| **Hrs/wk** | 1 |
| **CP** | 1 |
| **Workload in Hours** | Independent Study Time 16, Study Time in Lecture 14 |
| **Lecturer** | Prof. Marcus Rutner |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

| Course L1660: Metallic Light-weight Materials | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Dr. Domonkos Tolnai |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | Lightweight construction<br>- Structural lightweight construction<br>- Material lightweight construction<br>- Choice criteria for metallic lightweight construction materials<br>Steel as lightweight construction materials<br>- Introduction to the fundamentals of steels<br>- Modern steels for the lightweight construction<br>- Fine grain steels<br>- High-strength low-alloyed steels<br>- Multi-phase steels (dual phase, TRIP)<br>- Weldability<br>- Applications<br><br>Aluminium alloys:<br>Introduction to the fundamentals of aluminium materials<br>Alloy systems<br>Non age-hardenable Al alloys: Processing and microstructure, mechanical qualities and applications<br>Age-hardenable Al alloys: Processing and microstructure, mechanical qualities and applications<br><br>Magnesium alloys<br>Introduction to the fundamental of magnesium materials<br>Alloy systems<br>Magnesium casting alloys, processing, microstructure and qualities<br>Magnesium wrought alloys, processing, microstructure and qualities<br>Examples of applications<br><br>Titanium alloys<br>Introduction to the fundamental of the titanium materials<br>Alloy systems<br>Processing, microstructure and properties<br>Examples of applications |

| | |
|---|---|
| | Exercises and excursions |
| **Literature** | George Krauss, Steels: Processing, Structure, and Performance, 978-0-87170-817-5 , 2006, 613 S.<br><br>Hans Berns, Werner Theisen, Ferrous Materials: Steel and Cast Iron, 2008. http://dx.doi.org/10.1007/978-3-540-71848-2<br><br>C. W. Wegst, Stahlschlüssel = Key to steel = La Clé des aciers = Chiave dell'acciaio = Liave del acero ISBN/ISSN: 3922599095<br><br>Bruno C., De Cooman / John G. Speer: Fundamentals of Steel Product Physical Metallurgy, 2011, 642 S.<br><br>Harry Chandler, Steel Metallurgy for the Non-Metallurgist 0-87170-652-0 , 2006, 84 S.<br><br>Catrin Kammer, Aluminium Taschenbuch 1, Grundlagen und Werkstoffe, Beuth, 16. Auflage 2009. 784 S., ISBN 978-3-410-22028-2<br><br>Günter Drossel, Susanne Friedrich, Catrin Kammer und Wolfgang Lehnert, Aluminium Taschenbuch 2, Umformung von Aluminium-Werkstoffen, Gießen von Aluminiumteilen, Oberflächenbehandlung von Aluminium, Recycling und Ökologie, Beuth, 16. Auflage 2009. 768 S., ISBN 978-3-410-22029-9<br><br>Catrin Kammer, Aluminium Taschenbuch 3, Weiterverarbeitung und Anwendung, Beuith,17. Auflage 2014. 892 S., ISBN 978-3-410-22311-5<br><br>G. Lütjering, J.C. Williams: Titanium, 2nd ed., Springer, Berlin, Heidelberg, 2007, ISBN 978-3-540-71397<br><br>Magnesium - Alloys and Technologies, K. U. Kainer (Hrsg.), Wiley-VCH, Weinheim 2003, ISBN 3-527-30570-x<br><br>Mihriban O. Pekguleryuz, Karl U. Kainer and Ali Kaya “Fundamentals of Magnesium Alloy Metallurgy”, Woodhead Publishing Ltd, 2013,ISBN 10: 0857090887 |

# Specialization Modeling

## Module M1151: Materials Modeling

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Material Modeling (L1535) | Lecture | 2 | 3 |
| Material Modeling (Exercise) (L1536) | Recitation Section (small) | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Christian Cyron |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics of mechanics as taught, e.g., in the modules Engineering Mechanics I and Engineering Mechanics II at TUHH (forces and moments, stress, linear strain, free-body principle, linear-elastic constitutive laws, strain energy); basics of mathematics as taught, e.g., in the modules Mathematics I and Mathematics II at TUHH |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students understand the theoretical foundations of anisotropic elasticity, viscoelasticity and elasto-plasticity in the realm of three-dimensional (linear) continuum mechanics. In the area of anisotropic elasticity, they know the concept of material symmetry and its application in orthotropic, transversely isotropic and isotropic materials. They understand the concept of stiffness and compliance and how both can be characterized by appropriate parameters. Moreover, the students understand viscoelasticity both in the time and frequency domain using the concepts of relaxation modulus, creep modulus, storage modulus and loss modulus. In the area of elasto-plasticity, the students know the concept of yield stress or (in higher dimensions) yield surface and of plastic potential. Additionally, the know the concepts of ideal plasticity, hardening and weakening. Moreover, they know von-Mises plasticity as a specific model of elasto-plasticity. |
| *Skills* | The students can independently identify and solve problems in the area of materials modeling and acquire the knowledge to do so. This holds in particular for the area fo anisotropically elastic, viscoelastic and elasto-plastic material behavior. In these areas, the students can independently develop models for complex material behavior. To this end, they have the ability to read and understand relevant literature and identify the relevant results reported there. Moreover, they can implement models which they developed or found in the literature in computational software (e.g., based on the finite element method) and use it for practical calculations. |
| **Personal Competence** | |
| *Social Competence* | The students are able to develop constitutive models for materials and present them to specialists. Moreover, they have the ability to discuss challenging problems of materials modeling with experts using the proper terminoloy, to identify and ask critical questions in such discussions and to identify and discuss potential caveats in models presented to them. |
| *Autonomy* | The students have the ability to independently develop abstract models that allow them to classify observed phenomena within an more general abstract framework and to predict their further evolution. Moreover, the students understand the advantages but also limitations of mathematical models and can thus independently decide when and to which extent they make sense as a basis for decisions. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 60 min |
| **Assignment for the Following Curricula** | Mechanical Engineering - Product Development and Production: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory<br>Product Development, Materials and Production: Core Qualification: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Product Development and Production: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory |

| Course L1535: Material Modeling | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Christian Cyron |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | One of the most important questions when modeling mechanical systems in practice is how to model the behavior of the materials of their different components. In addition to simple isotropic elasticity in particular the following phenomena play key roles<br><br>- anisotropy (material behavior depending on direction, e.g., in fiber-reinforced materials)<br>- plasticity (permanent deformation due to one-time overload, e.g., in metal forming)<br>- viscoelasticity (absorption of energy, e.g., in dampers)<br>- creep (slow deformation under permanent load, e.g., in pipes)<br><br>This lecture briefly introduces the theoretical foundations and mathematical modeling of the above phenomena. It is complemented by exercises where simple examples problems are solved by calculations and where the implementation of the content of the lecture in computer simulations is explained. It will also briefly discussed how important material parameters can be determined from experimental data. |
| **Literature** | Empfohlene Literatur / Recommended literature:<br>1) Dietmar Gross, Werner Hauger, Peter Wriggers, Technische Mechanik 4, Springer 2018, DOI: 10.1007/978-3-662-55694-8<br>2) Peter Haupt, Continuum Mechanics and Theory of Materials, Springer 2002, DOI: 10.1007/978-3-662-04775-0 |

| Course L1536: Material Modeling (Exercise) | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Christian Cyron, Daniel Paukner |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | One of the most important questions when modeling mechanical systems in practice is how to model the behavior of the materials of their different components. In addition to simple isotropic elasticity in particular the following phenomena play key roles<br><br>- anisotropy (material behavior depending on direction, e.g., in fiber-reinforced materials)<br>- plasticity (permanent deformation due to one-time overload, e.g., in metal forming)<br>- viscoelasticity (absorption of energy, e.g., in dampers)<br>- creep (slow deformation under permanent load, e.g., in pipes)<br><br>This lecture briefly introduces the theoretical foundations and mathematical modeling of the above phenomena. It is complemented by exercises where simple examples problems are solved by calculations and where the implementation of the content of the lecture in computer simulations is explained. It will also briefly discussed how important material parameters can be determined from experimental data. |
| **Literature** | Empfohlene Literatur / Recommended literature:<br>1) Dietmar Gross, Werner Hauger, Peter Wriggers, Technische Mechanik 4, Springer 2018, DOI: 10.1007/978-3-662-55694-8<br>2) Peter Haupt, Continuum Mechanics and Theory of Materials, Springer 2002, DOI: 10.1007/978-3-662-04775-0 |

## Module M0604: High-Order FEM

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| High-Order FEM (L0280) | Lecture | 3 | 4 |
| High-Order FEM (L0281) | Recitation Section (large) | 1 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Alexander Düster |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge of partial differential equations is recommended. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able to<br>+ give an overview of the different (h, p, hp) finite element procedures.<br>+ explain high-order finite element procedures.<br>+ specify problems of finite element procedures, to identify them in a given situation and to explain their mathematical and mechanical background. |
| *Skills* | Students are able to<br>+ apply high-order finite elements to problems of structural mechanics.<br>+ select for a given problem of structural mechanics a suitable finite element procedure.<br>+ critically judge results of high-order finite elements.<br>+ transfer their knowledge of high-order finite elements to new problems. |
| **Personal Competence** | |
| *Social Competence* | Students are able to<br>+ solve problems in heterogeneous groups.<br>+ present and discuss their results in front of others.<br>+ give and accept professional constructive criticism. |
| *Autonomy* | Students are able to<br>+ assess their knowledge by means of exercises and E-Learning.<br>+ acquaint themselves with the necessary knowledge to solve research oriented tasks.<br>+ to transform the acquired knowledge to similar problems. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | Compulsory: No; Bonus: 10 %; Form: Presentation; Description: Forschendes Lernen |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Civil Engineering: Specialisation Computational Engineering: Elective Compulsory<br>Computational Engineering: Core Qualification: Elective Compulsory<br>International Management and Engineering: Specialisation II. Product Development and Production: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory<br>Mechatronics: Technical Complementary Course: Elective Compulsory<br>Product Development, Materials and Production: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Technomathematics: Specialisation III. Engineering Science: Elective Compulsory<br>Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory |

| Course L0280: High-Order FEM | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 78, Study Time in Lecture 42 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | 1. Introduction<br>2. Motivation<br>3. Hierarchic shape functions<br>4. Mapping functions<br>5. Computation of element matrices, assembly, constraint enforcement and solution<br>6. Convergence characteristics<br>7. Mechanical models and finite elements for thin-walled structures<br>8. Computation of thin-walled structures<br>9. Error estimation and hp-adaptivity<br>10. High-order fictitious domain methods |
| **Literature** | [1] Alexander Düster, High-Order FEM, Lecture Notes, Technische Universität Hamburg-Harburg, 164 pages, 2014<br>[2] Barna Szabo, Ivo Babuska, Introduction to Finite Element Analysis – Formulation, Verification and Validation, John Wiley & Sons, 2011 |

| Course L0281: High-Order FEM | |
|---|---|
| **Typ** | Recitation Section (large) |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M0606: Numerical Algorithms in Structural Mechanics

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Numerical Algorithms in Structural Mechanics (L0284) | Lecture | 2 | 3 |
| Numerical Algorithms in Structural Mechanics (L0285) | Recitation Section (small) | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Alexander Düster |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge of partial differential equations is recommended. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able to<br>+ give an overview of the standard algorithms that are used in finite element programs.<br>+ explain the structure and algorithm of finite element programs.<br>+ specify problems of numerical algorithms, to identify them in a given situation and to explain their mathematical and computer science background. |
| *Skills* | Students are able to<br>+ construct algorithms for given numerical methods.<br>+ select for a given problem of structural mechanics a suitable algorithm.<br>+ apply numerical algorithms to solve problems of structural mechanics.<br>+ implement algorithms in a high-level programming languate (here C++).<br>+ critically judge and verfiy numerical algorithms. |
| **Personal Competence** | |
| *Social Competence* | Students are able to<br>+ solve problems in heterogeneous groups.<br>+ present and discuss their results in front of others.<br>+ give and accept professional constructive criticism. |
| *Autonomy* | Students are able to<br>+ assess their knowledge by means of exercises and E-Learning.<br>+ acquaint themselves with the necessary knowledge to solve research oriented tasks.<br>+ to transform the acquired knowledge to similar problems. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 2h |
| **Assignment for the Following Curricula** | Civil Engineering: Specialisation Computational Engineering: Elective Compulsory<br>Computational Engineering: Core Qualification: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Product Development, Materials and Production: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Technomathematics: Specialisation III. Engineering Science: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory |

| Course L0284: Numerical Algorithms in Structural Mechanics | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | 1. Motivation<br>2. Basics of C++<br>3. Numerical integration<br>4. Solution of nonlinear problems<br>5. Solution of linear equation systems<br>6. Verification of numerical algorithms<br>7. Selected algorithms and data structures of a finite element code |
| **Literature** | [1] D. Yang, C++ and object-oriented numeric computing, Springer, 2001.<br>[2] K.-J. Bathe, Finite-Elemente-Methoden, Springer, 2002. |

| Course L0285: Numerical Algorithms in Structural Mechanics | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M0605: Computational Structural Dynamics

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Computational Structural Dynamics (L0282) | Lecture | 3 | 4 |
| Computational Structural Dynamics (L0283) | Recitation Section (small) | 1 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Alexander Düster |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge of partial differential equations is recommended. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able to<br>+ give an overview of the computational procedures for problems of structural dynamics.<br>+ explain the application of finite element programs to solve problems of structural dynamics.<br>+ specify problems of computational structural dynamics, to identify them in a given situation and to explain their mathematical and mechanical background. |
| *Skills* | Students are able to<br>+ model problems of structural dynamics.<br>+ select a suitable solution procedure for a given problem of structural dynamics.<br>+ apply computational procedures to solve problems of structural dynamics.<br>+ verify and critically judge results of computational structural dynamics. |
| **Personal Competence** | |
| *Social Competence* | Students are able to<br>+ solve problems in heterogeneous groups.<br>+ present and discuss their results in front of others.<br>+ give and accept professional constructive criticism. |
| *Autonomy* | Students are able to<br>+ assess their knowledge by means of exercises and E-Learning.<br>+ acquaint themselves with the necessary knowledge to solve research oriented tasks.<br>+ to transform the acquired knowledge to similar problems. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 2h |
| **Assignment for the Following Curricula** | Civil Engineering: Specialisation Computational Engineering: Elective Compulsory<br>Computational Engineering: Core Qualification: Elective Compulsory<br>International Management and Engineering: Specialisation II. Mechatronics: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Mechatronics: Technical Complementary Course: Elective Compulsory<br>Product Development, Materials and Production: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory |

| Course L0282: Computational Structural Dynamics | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 78, Study Time in Lecture 42 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | 1. Motivation<br>2. Basics of dynamics<br>3. Time integration methods<br>4. Modal analysis<br>5. Fourier transform<br>6. Applications |
| **Literature** | [1] K.-J. Bathe, Finite-Elemente-Methoden, Springer, 2002.<br>[2] J.L. Humar, Dynamics of Structures, Taylor & Francis, 2012. |

| Course L0283: Computational Structural Dynamics | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M1238: Quantum Mechanics of Solids

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Quantum Mechanics of Solids (L1675) | Lecture | 2 | 4 |
| Quantum Mechanics of Solids (L1676) | Recitation Section (small) | 1 | 2 |

| | |
|---|---|
| **Module Responsible** | Dr. Gregor Vonbun-Feldbauer |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge of advanced mathematics like analysis, linear algebra, differential equations and complex functions, e.g., Mathematics I-IV<br>Knowledge of mechanics and physics, particularly solid state physics, e.g., Materials Physics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The master students will be able to explain...<br>...the basics of quantum mechanics.<br>... the importance of quantum physics for the description of materials properties.<br>... correlations between on quantum mechanics based phenomena between individual atoms and macroscopic properties of materials.<br>The master students will then be able to connect essential materials properties in engineering with materials properties on the atomistic scale in order to understand these connections. |
| *Skills* | After attending this lecture the students can ...<br>...perform materials design on a quantum mechanical basis. |
| **Personal Competence** | |
| *Social Competence* | The students are able to discuss competently quantum-mechanics-based subjects with experts from fields such as physics and materials science. |
| *Autonomy* | The students are able to independently develop solutions to quantum mechanical problems. They can also acquire the knowledge they need to deal with more complex questions with a quantum mechanical background from the literature. |
| **Workload in Hours** | Independent Study Time 138, Study Time in Lecture 42 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Oral exam |
| **Examination duration and scale** | 25 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

| Course L1675: Quantum Mechanics of Solids | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 92, Study Time in Lecture 28 |
| **Lecturer** | Dr. Gregor Vonbun-Feldbauer |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | 1. Introduction<br>1.1 Relevance of Quantum Mechanics<br>1.2 Classification of Solids<br><br>2. Foundations of Quantum Mechanics<br>2.1 Reminder : Elements of Classical Mechanics<br>2.2 Motivation for Quantum Mechanics<br>2.3 Particle-Wave Duality<br>2.4 Formalism<br><br>3. Elementary QM Problems<br>3.1 Onedimensional Problems of a Particle in a Potential<br>3.2 Two-Level System<br>3.3 Harmonic Oscillator<br>3.4 Electrons in a Magnetic Field<br>3.5 Hydrogen Atom<br><br>4. Quantum Effects in Condensed Matter<br>4.1 Preliminary<br>4.2 Electronic Levels<br>4.3 Magnetism<br>4.4 Superconductivity<br>4.5 Quantum Hall Effect |
| **Literature** | Physik für Ingenieure, Hering/Martin/Stohrer, Springer<br><br>Atom- und Quantenphysik, Haken/Wolf, Springer<br><br>Grundkurs Theoretische Physik 5\|1, Nolting, Springer<br><br>Electronic Structure of Materials, Sutton, Oxford<br><br>Materials Science and Engineering: An Introduction, Callister/Rethwisch, Edition 9, Wiley |

| Course L1676: Quantum Mechanics of Solids | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | Dr. Gregor Vonbun-Feldbauer |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M1915: Materials Science Seminar

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Seminar (L1757) | Seminar | 2 | 3 |
| Seminar Composites (L1758) | Seminar | 2 | 3 |
| Seminar Advanced Ceramics (L1801) | Seminar | 2 | 3 |
| Seminar on interface-dominated materials (L1795) | Seminar | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Jörg Weißmüller |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Fundamental knowledge on nanomaterials, electrochemistry, interface science, mechanics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain the most important facts and relationships of a specific topic from the field of materials science. |
| *Skills* | Students are able to compile a specified topic from the field of materials science and to give a clear, structured and comprehensible presentation of the subject. They can comply with a given duration of the presentation. They can write in English a summary including illustrations that contains the most important results, relationships and explanations of the subject. |
| **Personal Competence** | |
| *Social Competence* | Students are able to adapt their presentation with respect to content, detailedness, and presentation style to the composition and previous knowledge of the audience. They can answer questions from the audience in a curt and precise manner. |
| *Autonomy* | Students are able to autonomously carry out a literature research concerning a given topic. They can independently evaluate the material. They can self-reliantly decide which parts of the material should be included in the presentation. |
| **Workload in Hours** | Depends on choice of courses |
| **Credit points** | 3 |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Modeling: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory |

### Course L1757: Seminar

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Jörg Weißmüller, Prof. Shan Shi |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | Current topics of materials research in the field of metallic nanomaterials. |
| **Literature** | Ausgehend von aktuellen Fachpublikationen erarbeiten die Studierenden unter Anleitung die wissenschaftlichen Grundlagen und stellen dazu die jeweils relevanten Arbeiten aus der Fachliteratur zusammen.<br><br>Based on current scientific publications, and under guidance, students work out the scientific fundamentals and compile the relevant works from the professional literature in each case. |

| Course L1758: Seminar Composites | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | Current topics in materials research in the field of polymers, their composites and nanomaterials. |
| **Literature** | Based on current scientific publications, and under guidance, students work out the scientific fundamentals and compile the relevant works from the professional literature in each case. |

| Course L1801: Seminar Advanced Ceramics | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Gerold Schneider, Prof. Kaline Pagnan Furlan |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | |
| **Literature** | |

| Course L1795: Seminar on interface-dominated materials | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Patrick Huber |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | |
| **Literature** | |

## Module M1150: Continuum Mechanics

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Continuum Mechanics (L1533) | Lecture | 2 | 3 |
| Continuum Mechanics (Exercise) (L1534) | Recitation Section (small) | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Christian Cyron |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics of mechanics as taught, e.g., in the modules Engineering Mechanics I and Engineering Mechanics II at TUHH (forces and moments, stress, linear strain, free-body principle, linear-elastic constitutive laws, strain energy); basics of mathematics as taught, e.g., in the modules Mathematics I and Mathematics II at TUHH |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | In this module, students learn the fundamental concepts of nonlinear continuum mechanics. This theory enables students to describe arbitrary deformations of continuous bodies (solid, liquid or gaseous) under arbitrary loads. The module is a continuation of the basic module Engineering Mechanics II (elastostatics), the limiting assumptions (isotropic, linear-elastic material behavior, small deformations, simple geometries) of which are successively eliminated.<br>First, the students learn the necessary fundamentals of tensor calculus. Based on this, the description of the deformations / strains of arbitrarily deformable bodies is dealt with. The students learn the mathematical formalism for characterizing the stress state of a body and for formulating the balance equations for mass, momentum, energy and entropy in various forms. Furthermore, the students know which constitutive assumptions have to be made for modeling the material behavior of a mechanical body. |
| *Skills* | The students can set up balance laws and apply basics of deformation theory to specific aspects, both in applied contexts as in research contexts. |
| **Personal Competence** | |
| *Social Competence* | The students are able to develop solutions also for complex problems of solid mechanics, to present them to specialists in written form and to develop ideas further. |
| *Autonomy* | The students are able to assess their own strengths and weaknesses. They can independently and on their own identify and solve problems in the area of continuum mechanics and acquire the knowledge required to this end. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 60 min |
| **Assignment for the Following Curricula** | Mechanical Engineering - Product Development and Production: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science: Specialisation Modeling: Elective Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory<br>Product Development, Materials and Production: Core Qualification: Elective Compulsory<br>Theoretical Mechanical Engineering: Core Qualification: Elective Compulsory |

| Course L1533: Continuum Mechanics | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Christian Cyron |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | Continuum mechanics is a general theory to describe the effect of mechanical forces on continuous mechanical (both solid and fluid) bodies. An important part of continuum mechanics is the mathematical description of strains and stresses as well as the stress-strain response of continuous mechanical bodies. The lecture continuum mechanics builds on the foundations tought in the lecture Engineering Mechanics II (Elastostatics) but extends them significantly. While in the lecture Engineering Mechanics II (Elastostatics) the focus was by and large limited to small deformations of simple bodies under simple loading, the lecture continuum mechanics introduces a general mathematical framework to deal with arbitrarily shaped bodies under arbitrary loading undergoing very general kinds of deformations. This lecture focuses primarily on theoretical aspects of continuum mechanics but its content is key to numerous applications in modern engineering, for example, in production, automotive, and biomedical engineering. The lecture covers:<br><br>• Fundamentals of tensor calculus<br>  ◦ Transformation invariance<br>  ◦ Tensor algebra<br>  ◦ Tensor analysis<br>• Kinematics<br>  ◦ Motion of continuum<br>  ◦ Deformation of infinitesimal line, area and volume elements<br>  ◦ Material and spatial description<br>  ◦ Polar decomposition<br>  ◦ Spectral decomposition<br>  ◦ Objectivity<br>  ◦ Strain measures<br>  ◦ Time derivatives<br>    ▪ Partial / material time derivatives<br>    ▪ Objective time rates<br>    ▪ Strain and deformation rates<br>  ◦ Transport theorems<br>• Balance equations (global and local form)<br>  ◦ Balance of mass<br>  ◦ The stress state<br>    ▪ Surface traction vectors<br>    ▪ Cauchy's fundamental theorem<br>    ▪ Stress tensors (Cauchy, 1. and 2. Piola-Kirchhoff, Kirchhoff stress tensor)<br>  ◦ Balance of linear momentum<br>  ◦ Balance of angular momentum<br>  ◦ Balance of energy<br>  ◦ Balance of entropy<br>  ◦ Clausius-Duhem inequality<br>• Constitutive laws<br>  ◦ Constitutive assumptions<br>  ◦ Fluids<br>  ◦ Elastic solids<br>    ▪ Hyperelasticity<br>    ▪ Material symmetry<br>  ◦ Elasto-plastic solids<br>• Analysis<br>  ◦ Initial-boundary value problems and their numerical solution |
| **Literature** | R. Greve: Kontinuumsmechanik: Ein Grundkurs für Ingenieure und Physiker<br><br>I-S. Liu: Continuum Mechanics, Springer |

| Course L1534: Continuum Mechanics (Exercise) | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Christian Cyron, Kian Philipp Abdolazizi |
| **Language** | DE |
| **Cycle** | WiSe |
| **Content** | The exercise on Continuum Mechanics explains the theoretical content of the lecture on Continuum Mechanics by way of a series of specific example problems. |
| **Literature** | R. Greve: Kontinuumsmechanik: Ein Grundkurs für Ingenieure und Physiker<br><br>I-S. Liu: Continuum Mechanics, Springer |

## Module M0603: Nonlinear Structural Analysis

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Nonlinear Structural Analysis (L0277) | Lecture | 3 | 4 |
| Nonlinear Structural Analysis (L0279) | Recitation Section (small) | 1 | 2 |

| | |
|---|---|
| **Module Responsible** | Prof. Alexander Düster |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge of partial differential equations is recommended. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able to<br>+ give an overview of the different nonlinear phenomena in structural mechanics.<br>+ explain the mechanical background of nonlinear phenomena in structural mechanics.<br>+ to specify problems of nonlinear structural analysis, to identify them in a given situation and to explain their mathematical and mechanical background. |
| *Skills* | Students are able to<br>+ model nonlinear structural problems.<br>+ select for a given nonlinear structural problem a suitable computational procedure.<br>+ apply finite element procedures for nonlinear structural analysis.<br>+ critically verify and judge results of nonlinear finite elements.<br>+ to transfer their knowledge of nonlinear solution procedures to new problems. |
| **Personal Competence** | |
| *Social Competence* | Students are able to<br>+ solve problems in heterogeneous groups.<br>+ present and discuss their results in front of others.<br>+ give and accept professional constructive criticism. |
| *Autonomy* | Students are able to<br>+ assess their knowledge by means of exercises and E-Learning.<br>+ acquaint themselves with the necessary knowledge to solve research oriented tasks.<br>+ to transform the acquired knowledge to similar problems. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 min |
| **Assignment for the Following Curricula** | Civil Engineering: Specialisation Structural Engineering: Elective Compulsory<br>Civil Engineering: Specialisation Computational Engineering: Compulsory<br>Computational Engineering: Core Qualification: Elective Compulsory<br>International Management and Engineering: Specialisation II. Civil Engineering: Elective Compulsory<br>Mechanical Engineering - Product Development and Production: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science: Specialisation Modeling: Elective Compulsory<br>Mechatronics: Technical Complementary Course: Elective Compulsory<br>Mechatronics: Core Qualification: Elective Compulsory<br>Product Development, Materials and Production: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Naval Architecture and Ocean Engineering: Core Qualification: Elective Compulsory<br>Ship and Offshore Technology: Core Qualification: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Simulation Technology: Elective Compulsory |

| Course L0277: Nonlinear Structural Analysis | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 78, Study Time in Lecture 42 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | 1. Introduction<br>2. Nonlinear phenomena<br>3. Mathematical preliminaries<br>4. Basic equations of continuum mechanics<br>5. Spatial discretization with finite elements<br>6. Solution of nonlinear systems of equations<br>7. Solution of elastoplastic problems<br>8. Stability problems<br>9. Contact problems |
| **Literature** | [1] Alexander Düster, Nonlinear Structrual Analysis, Lecture Notes, Technische Universität Hamburg-Harburg, 2014.<br>[2] Peter Wriggers, Nonlinear Finite Element Methods, Springer 2008.<br>[3] Peter Wriggers, Nichtlineare Finite-Elemente-Methoden, Springer 2001.<br>[4] Javier Bonet and Richard D. Wood, Nonlinear Continuum Mechanics for Finite Element Analysis, Cambridge University Press, 2008. |

| Course L0279: Nonlinear Structural Analysis | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | Prof. Alexander Düster |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M1807: Machine Learning for Physical Systems

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Machine Learning for Physical Systems (L2987) | Lecture | 2 | 3 |
| Machine Learning for Physical Systems (L2988) | Project-/problem-based Learning | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Roland Can Aydin |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Prior knowledge in machine learning or Python programming is highly recommended, in particular a certain level of experience with standard ML libraries in Python (preferably PyTorch). No prior knowledge of specialized ML architectures, such as PINNs or large language models, is necessary. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | In this module, students will delve into the advanced integration of machine learning techniques with physical systems. The course covers sophisticated topics, demonstrating how cutting-edge machine learning methodologies can be applied not only in general domains but are specifically tailored for complex physical systems. Core areas of study include:<br><br>- Advanced Data Management**:** How can domain knowledge relating to physical problems be integrated into the pre- and postprocessing of data?<br><br>- Transformer Architectures: Understanding the design and application of transformer models and large language models, focusing on their suitability to physical systems (e.g., Foundation models)<br><br>- Physics-Informed Neural Networks: Architectures for embedding physical laws into a neural network's loss function<br><br>- Constitutive Artificial Neural Networks: Architectures for embedding physical laws within a neural network's topology<br><br>- Feature selection and dimensionality reduction<br><br>- ML for Molecular Dynamics and Simulation<br><br>- Synthetic Data Generation, particularly its usage to augment physical experiments (which are often a bottleneck in data generation)<br><br>- Optimal Experimental Design: Techniques for efficiently gathering data through intelligently designed experiments.<br><br>- Process-Structure-Properties Pipelines: Exploring specialised microstructural descriptors such as Gram-matrices to connect structure to either process parameters or mechanical properties<br><br>Complementing the lectures, the associated exercise sessions will use various Python libraries such as Sklearn and Pytorch, typically within Jupyter notebooks. These practical sessions are designed to reinforce the concepts discussed in the lectures, with a reciprocal relationship between the theoretical and practical aspects of the course.<br><br>This course is designed for those looking to understand and apply machine learning in the realm of physical systems, bridging the gap between abstract algorithms and real-world physical phenomena. The course is offered fully in English. |
| *Skills* | The students will be able to competently evaluate suitable machine learning methods for a given problem involving physical systems, understanding the advantages and disadvantages of each approach. They will be able to do so both for standard machine learning tools and methods as well as for specialised models. |
| **Personal Competence** | |
| *Social Competence* | The students will be able to reason for and against solutions for complex problems involving physical systems and to present their conclusions on how to incorporate their domain knowledge to facilitate the choice, design, training, and validation of an appropriate machine learning algorithm. |
| *Autonomy* | The module places a particular emphasis on enabling students to achieve the competence level both in group work (homework assignments) as well as individually (during the exercises). |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |

**Course achievement**

| Compulsory | Bonus | Form | Description |
|---|---|---|---|
| No | 20 % | Excercises | Im Rahmen der Übung und über Stud.IP werden wöchentliche Übungsaufgaben bereitgestellt, durch deren korrekte Abgabe bis zu 20% als Bonus zur Abschlussprüfung erbracht werden können. |

| | |
|---|---|
| **Examination** | Written exam |
| **Examination duration and scale** | 75 min |
| **Assignment for the Following Curricula** | General Engineering Science (German program, 7 semester): Specialisation Data Science: Elective Compulsory<br>General Engineering Science (German program, 7 semester): Specialisation Advanced Materials: Compulsory<br>General Engineering Science (German program, 7 semester): Specialisation Mechanical Engineering, Focus Mechatronics: Elective Compulsory<br>General Engineering Science (German program, 7 semester): Specialisation Mechanical Engineering, Focus Theoretical Mechanical Engineering: Elective Compulsory<br>Computational Engineering: Core Qualification: Elective Compulsory<br>Data Science: Specialisation III. Applications: Elective Compulsory |

| | |
|---|---|
| | Energy Systems: Core Qualification: Elective Compulsory<br>Engineering Science: Specialisation Advanced Materials: Compulsory<br>Engineering Science: Specialisation Data Science: Elective Compulsory<br>Aeronautics: Core Qualification: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Mechatronics: Specialisation Dynamic Systems and AI: Elective Compulsory<br>Mechatronics: Specialisation Robot- and Machine-Systems: Elective Compulsory |

| Course L2987: Machine Learning for Physical Systems | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Roland Can Aydin |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | In this lecture, students will delve into the advanced integration of machine learning techniques with physical systems. The lecture covers sophisticated topics, demonstrating how cutting-edge machine learning methodologies can be applied not only in general domains but are specifically tailored for complex physical systems. Core areas of study include:<br><br>- Advanced Data Management**:** How can domain knowledge relating to physical problems be integrated into the pre- and postprocessing of data?<br><br>- Transformer Architectures: Understanding the design and application of transformer models and large language models, focusing on their suitability to physical systems (e.g., Foundation models)<br><br>- Physics-Informed Neural Networks: Architectures for embedding physical laws into a neural network's loss function<br><br>- Constitutive Artificial Neural Networks: Architectures for embedding physical laws within a neural network's topology<br><br>- Feature selection and dimensionality reduction<br><br>- ML for Molecular Dynamics and Simulation<br><br>- Synthetic Data Generation, particularly its usage to augment physical experiments (which are often a bottleneck in data generation)<br><br>- Optimal Experimental Design: Techniques for efficiently gathering data through intelligently designed experiments.<br><br>- Process-Structure-Properties Pipelines: Exploring specialised microstructural descriptors such as Gram-matrices to connect structure to either process parameters or mechanical properties<br><br>This lecture is designed for those looking to understand and apply machine learning in the realm of physical systems, bridging the gap between abstract algorithms and real-world physical phenomena. The lecture is offered fully in English. |
| **Literature** | Relevante Literatur basiert vor allem auf wissenschaftlichen Veröffentlichungen (statt Lehrbüchern), die jeweiligen Referenzen werden in der Vorlesung bzw. Übung genannt. |

| Course L2988: Machine Learning for Physical Systems | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Roland Can Aydin |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | The exercise (PBL) demonstrates the methods introduced in the lecture on different example applications, focusing on gaining practical hands-on proficiency. By submitting correctly solved homework assignments, points can be earned for the module examination. Topics correspond to those presented at that time in the module's lecture. |
| **Literature** | Keine über die in der Vorlesung genannten Referenzen herausgehende Literatur ist notwendig. |

## Specialization Nano and Hybrid Materials

### Module M1334: BIO II: Biomaterials

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Biomaterials (L0593) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Franziska Lissel |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge of orthopedic and surgical techniques is recommended. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students can describe the materials of the human body and the materials being used in medical engineering, and their fields of use. |
| *Skills* | The students can explain the advantages and disadvantages of different kinds of biomaterials. |
| **Personal Competence** | |
| *Social Competence* | The students are able to discuss issues related to materials being present or being used for replacements with student mates and the teachers. |
| *Autonomy* | The students are able to acquire information on their own. They can also judge the information with respect to its credibility. |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Credit points** | 3 |
| **Course achievement** | **Compulsory** Yes; **Bonus** 10 %; **Form** Presentation; **Description** |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory<br>International Management and Engineering: Specialisation II. Medical Engineering: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Mechatronics: Specialisation Medical Engineering: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Compulsory<br>Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory |

| Course L0593: Biomaterials | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Franziska Lissel, Prof. Shan Shi |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | Topics to be covered include:<br><br>1. Introduction (Importance, nomenclature, relations)<br><br>2. Biological materials<br><br>2.1 Basics (components, testing methods)<br><br>2.2 Bone (composition, development, properties, influencing factors)<br><br>2.3 Cartilage (composition, development, structure, properties, influencing factors)<br><br>2.4 Fluids (blood, synovial fluid)<br><br>3 Biological structures<br><br>3.1 Menisci of the knee joint<br><br>3.2 Intervertebral discs<br><br>3.3 Teeth<br><br>3.4 Ligaments<br><br>3.5 Tendons<br><br>3.6 Skin<br><br>3.7 Nervs<br><br>3.8 Muscles<br><br>4. Replacement materials<br><br>4.1 Basics (history, requirements, norms)<br><br>4.2 Steel (alloys, properties, reaction of the body)<br><br>4.3 Titan (alloys, properties, reaction of the body)<br><br>4.4 Ceramics and glas (properties, reaction of the body)<br><br>4.5 Plastics (properties of PMMA, HDPE, PET, reaction of the body)<br><br>4.6 Natural replacement materials<br><br>Knowledge of composition, structure, properties, function and changes/adaptations of biological and technical materials (which are used for replacements in-vivo). Acquisition of basics for theses work in the area of biomechanics. |
| **Literature** | Hastings G and Ducheyne P.: Natural and living biomaterials. Boca Raton: CRC Press, 1984.<br><br>Williams D.: Definitions in biomaterials. Oxford: Elsevier, 1987.<br><br>Hastings G.: Mechanical properties of biomaterials: proceedings held at Keele University, September 1978. New York: Wiley, 1998.<br><br>Black J.: Orthopaedic biomaterials in research and practice. New York: Churchill Livingstone, 1988.<br><br>Park J. Biomaterials: an introduction. New York: Plenum Press, 1980.<br><br>Wintermantel, E. und Ha, S.-W : Biokompatible Werkstoffe und Bauweisen. Berlin, Springer, 1996. |

## Module M0766: Microsystems Technology

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Microsystems Technology (L0724) | Lecture | 2 | 4 |

| | |
|---|---|
| **Module Responsible** | Prof. Hoc Khiem Trieu |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics in physics, chemistry and semiconductor technology |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able<br>• to present and to explain current fabrication techniques for microstructures and especially methods for the fabrication of microsensors and microactuators, as well as the integration thereof in more complex systems<br>• to explain in details operation principles of microsensors and microactuators and<br>• to discuss the potential and limitation of microsystems in application. |
| *Skills* | Students are capable<br>• to analyze the feasibility of microsystems,<br>• to develop process flows for the fabrication of microstructures and<br>• to apply them. |
| **Personal Competence** | |
| *Social Competence* | None |
| *Autonomy* | The independence of the students is demanded and promoted in that they have to transfer and apply what they have learned to ever new boundary conditions. This requirement is communicated at the beginning of the semester and consistently practiced until the exam. Students are encouraged to work independently by not being given a solution, but by learning to work out the solution step by step by asking specific questions. Students learn to ask questions independently when they are faced with a problem. They learn to independently break down problems into manageable sub-problems. |
| **Workload in Hours** | Independent Study Time 92, Study Time in Lecture 28 |
| **Credit points** | 4 |
| **Course achievement** | None |
| **Examination** | Oral exam |
| **Examination duration and scale** | 30 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory |

| Course L0724: Microsystems Technology | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 92, Study Time in Lecture 28 |
| **Lecturer** | Prof. Hoc Khiem Trieu |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | • Introduction (historical view, scientific and economic relevance, scaling laws)<br>• Semiconductor Technology Basics, Lithography (wafer fabrication, photolithography, improving resolution, next-generation lithography, nano-imprinting, molecular imprinting)<br>• Deposition Techniques (thermal oxidation, epitaxy, electroplating, PVD techniques: evaporation and sputtering; CVD techniques: APCVD, LPCVD, PECVD and LECVD; screen printing)<br>• Etching and Bulk Micromachining (definitions, wet chemical etching, isotropic etch with HNA, electrochemical etching, anisotropic etching with KOH/TMAH: theory, corner undercutting, measures for compensation and etch-stop techniques; plasma processes, dry etching: back sputtering, plasma etching, RIE, Bosch process, cryo process, XeF2 etching)<br>• Surface Micromachining and alternative Techniques (sacrificial etching, film stress, stiction: theory and counter measures; Origami microstructures, Epi-Poly, porous silicon, SOI, SCREAM process, LIGA, SU8, rapid prototyping)<br>• Thermal and Radiation Sensors (temperature measurement, self-generating sensors: Seebeck effect and thermopile; modulating sensors: thermo resistor, Pt-100, spreading resistance sensor, pn junction, NTC and PTC; thermal anemometer, mass flow sensor, photometry, radiometry, IR sensor: thermopile and bolometer)<br>• Mechanical Sensors (strain based and stress based principle, capacitive readout, piezoresistivity, pressure sensor: piezoresistive, capacitive and fabrication process; accelerometer: piezoresistive, piezoelectric and capacitive; angular rate sensor: operating principle and fabrication process)<br>• Magnetic Sensors (galvanomagnetic sensors: spinning current Hall sensor and magneto-transistor; magnetoresistive sensors: magneto resistance, AMR and GMR, fluxgate magnetometer)<br>• Chemical and Bio Sensors (thermal gas sensors: pellistor and thermal conductivity sensor; metal oxide semiconductor gas sensor, organic semiconductor gas sensor, Lambda probe, MOSFET gas sensor, pH-FET, SAW sensor, principle of biosensor, Clark electrode, enzyme electrode, DNA chip)<br>• Micro Actuators, Microfluidics and TAS (drives: thermal, electrostatic, piezo electric and electromagnetic; light modulators, DMD, adaptive optics, microscanner, microvalves: passive and active, micropumps, valveless micropump, electrokinetic micropumps, micromixer, filter, inkjet printhead, microdispenser, microfluidic switching elements, microreactor, lab-on-a-chip, microanalytics)<br>• MEMS in medical Engineering (wireless energy and data transmission, smart pill, implantable drug delivery system, stimulators: microelectrodes, cochlear and retinal implant; implantable pressure sensors, intelligent osteosynthesis, implant for spinal cord regeneration)<br>• Design, Simulation, Test (development and design flows, bottom-up approach, top-down approach, testability, modelling: multiphysics, FEM and equivalent circuit simulation; reliability test, physics-of-failure, Arrhenius equation, bath-tub relationship)<br>• System Integration (monolithic and hybrid integration, assembly and packaging, dicing, electrical contact: wire bonding, TAB and flip chip bonding; packages, chip-on-board, wafer-level-package, 3D integration, wafer bonding: anodic bonding and silicon fusion bonding; micro electroplating, 3D-MID) |
| **Literature** | M. Madou: Fundamentals of Microfabrication, CRC Press, 2002<br><br>N. Schwesinger: Lehrbuch Mikrosystemtechnik, Oldenbourg Verlag, 2009<br><br>T. M. Adams, R. A. Layton:Introductory MEMS, Springer, 2010<br><br>G. Gerlach; W. Dötzel: Introduction to microsystem technology, Wiley, 2008 |

## Module M1335: BIO II: Artificial Joint Replacement

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Artificial Joint Replacement (L1306) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Sara Checa Esteban |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge of orthopedic and surgical techniques and mechanical basics is recommended. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students are able to explain the diseases and injuries that can make joint replacement necessary. In addition, students know the surgical alternatives. |
| *Skills* | The students can explain the advantages and disadvantages of different kinds of endoprotheses. |
| **Personal Competence** | |
| *Social Competence* | The students are able to discuss issues related to endoprothese with student mates and the teachers. |
| *Autonomy* | The students are able to acquire information on their own. They can also judge the information with respect to its credibility. |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Credit points** | 3 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory<br>International Management and Engineering: Specialisation II. Medical Engineering: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory<br>Orientation Studies: Core Qualification: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Bio- and Medical Technology: Elective Compulsory |

### Course L1306: Artificial Joint Replacement

| | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Sara Checa Esteban |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | Contents<br><br>1. INTRODUCTION (meaning, aim, basics, general history of the artificial joint replacement)<br><br>2. FUNCTIONAL ANALYSIS (The human gait, human work, sports activity)<br><br>3. THE HIP JOINT (anatomy, biomechanics, joint replacement of the shaft side and the socket side, evolution of implants)<br><br>4. THE KNEE JOINT (anatomy, biomechanics, ligament replacement, joint replacement femoral, tibial and patellar components)<br><br>5. THE FOOT (anatomy, biomechanics, joint replacement, orthopedic procedures)<br><br>6. THE SHOULDER (anatomy, biomechanics, joint replacement)<br><br>7. THE ELBOW (anatomy, biomechanics, joint replacement)<br><br>8. THE HAND (anatomy, biomechanics, joint replacement)<br><br>9. TRIBOLOGY OF NATURAL AND ARTIFICIAL JOINTS (corrosion, friction, wear) |
| **Literature** | Kapandji, I..: Funktionelle Anatomie der Gelenke (Band 1-4), Enke Verlag, Stuttgart, 1984.<br><br>Nigg, B., Herzog, W.: Biomechanics of the musculo-skeletal system, John Wiley&Sons, New York 1994<br><br>Nordin, M., Frankel, V.: Basic Biomechanics of the Musculoskeletal System, Lea&Febiger, Philadelphia, 1989.<br><br>Czichos, H.: Tribologiehandbuch, Vieweg, Wiesbaden, 2003.<br><br>Sobotta und Netter für Anatomie der Gelenke |

## Module M1220: Interfaces and interface-dominated Materials

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Nature's Hierarchical Materials (L1663) | Seminar | 2 | 3 |
| Interfaces (L1654) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Patrick Huber |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge in Materials Science, e.g. Materials Science I/II, and physical chemistry |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The students will be able to explain the structural and thermodynamic properties of interfaces in comparison to the bulk systems. They will be able to describe the relevance of interfaces and physico-chemical modifications of interfaces. Moreover, they are able to outline the characteristics of biomaterials and to relate them to classical materials systems, such as metals, ceramics and polymers. |
| *Skills* | The students are able to rationalize the impact of interfaces on material properties and functionalities. Moreover, they are able to trace the peculiar properties of biomaterials to their hierarchical hybrid structure. |
| **Personal Competence** | |
| *Social Competence* | The students are able to present solutions to specialists and to develop ideas further. |
| *Autonomy* | The students are able to ...<br>• assess their own strengths and weaknesses.<br>• define tasks independently. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 90 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Mechanical Engineering and Management: Specialisation Product Engineering: Elective Compulsory |

### Course L1663: Nature's Hierarchical Materials

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | NN |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | Nature hierarchical materials are omnipresent in the world around us, being fundamental for both the plants and animal kingdoms. Nature engineering is quite impressive since nature uses only a small variety of building blocks (minerals, proteins and sugar) and yet, is capable of producing an incredible large number of structures with different functions, i.e. multifunctional materials. This is one of the reasons why materials science and engineering research on bioinspiration or biomimicry has been increasing significantly over the past 20 years. Moreover, the scientists and engineers have one major advantage over nature: they can combine bioinspiration with a wide variety of other building blocks (metals, ceramics, polymers and derived composites). The main goal of this seminar series is to provide an introduction about the state of the art on bioinspired materials from an engineering point of view, while providing students opportunities to develop skills relevant to their master thesis work such as proper literature search, systematic literature review, presentation preparation and presentation - all connected to the main topic of Nature hierarchical materials.<br>. |
| **Literature** | Peter Fratzl and Richard Weinkamer. Nature’s hierarchical materials. Progress in Materials Science 52 (2007) 1263-1334<br>Journal publications |

| Course L1654: Interfaces | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Patrick Huber |
| **Language** | DE |
| **Cycle** | SoSe |
| **Content** | • Microscopic structure and thermodynamics of interfaces (gas/solid, gas/liquid, liquid/liquid, liquid/solid)<br>• Experimental methods for the study of interfaces<br>• Interfacial forces<br>• wetting<br>• surfactants, foams, bio-membranes<br>• chemical grafting of interfaces |
| **Literature** | "Physics and Chemistry of Interfaces", K.H. Butt, K. Graf, M. Kappl, Wiley-VCH Weinheim (2006)<br><br>"Interfacial Science", G.T. Barnes, I.R. Gentle, Oxford University Press (2005) |

## Module M0930: Semiconductor Seminar

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |
| Semiconductor Seminar (L0760) | Seminar | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Hoc Khiem Trieu |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Semiconductors |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain the most important facts and relationships of a specific topic from the field of semiconductors. |
| *Skills* | Students are able to compile a specified topic from the field of semiconductors and to give a clear, structured and comprehensible presentation of the subject. They can comply with a given duration of the presentation. They can write in English a summary including illustrations that contains the most important results, relationships and explanations of the subject. |
| **Personal Competence** | |
| *Social Competence* | Students are able to adapt their presentation with respect to content, detailedness, and presentation style to the composition and previous knowledge of the audience. They can answer questions from the audience in a curt and precise manner. |
| *Autonomy* | Students are able to autonomously carry out a literature research concerning a given topic. They can independently evaluate the material. They can self-reliantly decide which parts of the material should be included in the presentation. |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Credit points** | 3 |
| **Course achievement** | None |
| **Examination** | Presentation |
| **Examination duration and scale** | 15 minutesw presentation + 5-10 minutes discussion + 2 pages written abstract |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory |

### Course L0760: Semiconductor Seminar

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Hoc Khiem Trieu, Dr. Alexander Petrov, Dr. Thomas Kusserow, Prof. Alexander Kölpin, Prof. Hoc Khiem Trieu, Prof. Manfred Eich |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | Prepare, present, and discuss talks about recent topics from the field of semiconductors. The presentations must be given in English.<br><br>***Evaluation Criteria:***<br><br>• understanding of subject, discussion, response to questions<br>• structure and logic of presentation (clarity, precision)<br>• coverage of the topic, selection of subjects presented<br>• linguistic presentation (clarity, comprehensibility)<br>• visual presentation (clarity, comprehensibility)<br>• handout (see below)<br>• compliance with timing requirement.<br><br>***Handout:***<br>Before your presentation, it is mandatory to distribute a printed handout (short abstract) of your presentation in English language. This must be no longer than two pages A4, and include the most important results, conclusions, explanations and diagrams. |
| **Literature** | Aktuelle Veröffentlichungen zu dem gewählten Thema |

## Module M0643: Optoelectronics I - Wave Optics

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Optoelectronics I: Wave Optics (L0359) | Lecture | 2 | 3 |
| Optoelectronics I: Wave Optics (Problem Solving Course) (L0361) | Recitation Section (small) | 1 | 1 |

| | |
|---|---|
| **Module Responsible** | Dr. Alexander Petrov |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basics in electrodynamics, calculus |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain the fundamental mathematical and physical relations of freely propagating optical waves.<br>They can give an overview on wave optical phenomena such as diffraction, reflection and refraction, etc.<br>Students can describe waveoptics based components such as electrooptical modulators in an application oriented way. |
| *Skills* | Students can generate models and derive mathematical descriptions in relation to free optical wave propagation.<br>They can derive approximative solutions and judge factors influential on the components' performance. |
| **Personal Competence** | |
| *Social Competence* | Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course. |
| *Autonomy* | Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures. |
| **Workload in Hours** | Independent Study Time 78, Study Time in Lecture 42 |
| **Credit points** | 4 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 60 minutes |
| **Assignment for the Following Curricula** | Electrical Engineering and Information Technology: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory<br>Electrical Engineering and Information Technology: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory<br>Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory<br>Renewable Energies: Specialisation Solar Energy Systems: Elective Compulsory |

| Course L0359: Optoelectronics I: Wave Optics | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Dr. Alexander Petrov |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | • Introduction to optics<br>• Electromagnetic theory of light<br>• Interference<br>• Coherence<br>• Diffraction<br>• Fourier optics<br>• Polarisation and Crystal optics<br>• Matrix formalism<br>• Reflection and transmission<br>• Complex refractive index<br>• Dispersion<br>• Modulation and switching of light |
| **Literature** | Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007<br>Hecht, E., Optics, Benjamin Cummings, 2001<br>Goodman, J.W. Statistical Optics, Wiley, 2000<br>Lauterborn, W., Kurz, T., Coherent Optics: Fundamentals and Applications, Springer, 2002 |

| Course L0361: Optoelectronics I: Wave Optics (Problem Solving Course) | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 1 |
| **CP** | 1 |
| **Workload in Hours** | Independent Study Time 16, Study Time in Lecture 14 |
| **Lecturer** | Dr. Alexander Petrov |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | see lecture Optoelectronics 1 - Wave Optics |
| **Literature** | see lecture Optoelectronics 1 - Wave Optics |

## Module M1238: Quantum Mechanics of Solids

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Quantum Mechanics of Solids (L1675) | Lecture | 2 | 4 |
| Quantum Mechanics of Solids (L1676) | Recitation Section (small) | 1 | 2 |

| | |
|---|---|
| **Module Responsible** | Dr. Gregor Vonbun-Feldbauer |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Knowledge of advanced mathematics like analysis, linear algebra, differential equations and complex functions, e.g., Mathematics I-IV<br>Knowledge of mechanics and physics, particularly solid state physics, e.g., Materials Physics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | The master students will be able to explain…<br>…the basics of quantum mechanics.<br>… the importance of quantum physics for the description of materials properties.<br>… correlations between on quantum mechanics based phenomena between individual atoms and macroscopic properties of materials.<br>The master students will then be able to connect essential materials properties in engineering with materials properties on the atomistic scale in order to understand these connections. |
| *Skills* | After attending this lecture the students can …<br>…perform materials design on a quantum mechanical basis. |
| **Personal Competence** | |
| *Social Competence* | The students are able to discuss competently quantum-mechanics-based subjects with experts from fields such as physics and materials science. |
| *Autonomy* | The students are able to independently develop solutions to quantum mechanical problems. They can also acquire the knowledge they need to deal with more complex questions with a quantum mechanical background from the literature. |
| **Workload in Hours** | Independent Study Time 138, Study Time in Lecture 42 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Oral exam |
| **Examination duration and scale** | 25 min |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Theoretical Mechanical Engineering: Specialisation Materials Science: Elective Compulsory |

| Course L1675: Quantum Mechanics of Solids | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 4 |
| **Workload in Hours** | Independent Study Time 92, Study Time in Lecture 28 |
| **Lecturer** | Dr. Gregor Vonbun-Feldbauer |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | 1. Introduction<br>1.1 Relevance of Quantum Mechanics<br>1.2 Classification of Solids<br><br>2. Foundations of Quantum Mechanics<br>2.1 Reminder : Elements of Classical Mechanics<br>2.2 Motivation for Quantum Mechanics<br>2.3 Particle-Wave Duality<br>2.4 Formalism<br><br>3. Elementary QM Problems<br>3.1 Onedimensional Problems of a Particle in a Potential<br>3.2 Two-Level System<br>3.3 Harmonic Oscillator<br>3.4 Electrons in a Magnetic Field<br>3.5 Hydrogen Atom<br><br>4. Quantum Effects in Condensed Matter<br>4.1 Preliminary<br>4.2 Electronic Levels<br>4.3 Magnetism<br>4.4 Superconductivity<br>4.5 Quantum Hall Effect |
| **Literature** | Physik für Ingenieure, Hering/Martin/Stohrer, Springer<br><br>Atom- und Quantenphysik, Haken/Wolf, Springer<br><br>Grundkurs Theoretische Physik 5\|1, Nolting, Springer<br><br>Electronic Structure of Materials, Sutton, Oxford<br><br>Materials Science and Engineering: An Introduction, Callister/Rethwisch, Edition 9, Wiley |

| Course L1676: Quantum Mechanics of Solids | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 1 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 46, Study Time in Lecture 14 |
| **Lecturer** | Dr. Gregor Vonbun-Feldbauer |
| **Language** | DE/EN |
| **Cycle** | SoSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

## Module M2111: Wearable Electronics: Development of soft and stretchable sensors and devices

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Wearable Electronics: Development of soft and stretchable sensors and devices (L3198) | Project-/problem-based Learning | 2 | 3 |
| Wearable Electronics: Materials and Applications (L3197) | Lecture | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Franziska Lissel |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | To successfully participate in this module, the following knowledge and skills are helpful but not mandatory:<br><br>- Basic knowledge of chemistry and physics, especially regarding polymers and electrical conductors.<br><br>- Interest in materials science and technology development.<br><br>- Ability to read and understand scientific texts in English.<br><br>- Willingness to collaborate in teams and solve technical and conceptual problems together.<br><br>- Basic skills in academic work (e.g., literature research, presentation).<br><br>This module is designed to be beginner-friendly. All essential foundations are covered during the course. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | 1. Understanding of the essential material properties of soft polymers (e.g., elasticity, conductivity) and their application in practice.<br><br>2. Ability to explain and apply the fundamentals of device design for organic field-effect transistors (OFETs) and organic electrochemical transistors (OECTs).<br><br>3. Development of solutions for specific challenges in soft electronics.<br><br>4. Critical evaluation of the societal, industrial, and scientific relevance of soft electronics technologies. |
| *Skills* | 1. Systematic development and theoretical design of simple devices (e.g., sensors, transistors).<br><br>2. Application of scientific methods to analyze material properties and devise design strategies. |
| **Personal Competence** | |
| *Social Competence* | 1. Ability to work effectively in teams, define roles, and distribute tasks.<br><br>2. Clear and persuasive communication of ideas and results in oral and written formats (e.g., presentations, reports).<br><br>3. Engagement with interdisciplinary questions and integration of diverse perspectives into problem-solving processes. |
| *Autonomy* | 1. Independent organization and execution of projects, including research and concept development.<br><br>2. Reflection on personal learning processes and effective use of feedback for improvement.<br><br>3. Development of innovative ideas to address technical and practical challenges. |
| **Workload in Hours** | Independent Study Time 124, Study Time in Lecture 56 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Presentation |
| **Examination duration and scale** | 20 min presentation followed by discussion |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory |

| Course L3198: Wearable Electronics: Development of soft and stretchable sensors and devices | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Franziska Lissel |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | In this module, you will learn the fundamentals of soft electronics and their application in innovative technologies such as wearables, health monitoring, and flexible displays. You will gain insight into the material properties of electrically conductive polymers and how to use them for flexible devices. Additionally, you will be introduced to the design principles of organic transistors (OFETs and OECTs) and explore the challenges in developing soft electronics. By the end of the module, you will be able to develop your own solutions for practical problems in this exciting field and reflect on the societal relevance of these technologies.<br><br>The module follows a Problem-Based Learning (PBL) format, where you will work in groups on a specific problem (e.g., a soft, stretchable sensor for health monitoring). In an asynchronous online seminar, you will receive feedback and guidance. At the end, you will present your results in a presentation, which also serves as the final exam.<br><br>**Overview Lecture: Wearable Electronics - Theoretical Foundations**<br><br>**Part 1: Introduction**<br>Overview of soft polymer electronics and their significance (wearables, health monitoring, flexible displays, robotics); introduction to organic electronics and the role of OFETs and OECTs. Introduction to the problem-based learning format.<br><br>**Part 2: Material Properties**<br>Electrically conductive polymers: properties, types, and processing; mechanical properties: elasticity, fracture strain, and criteria for selecting materials for flexible devices; trade-offs between conductivity and flexibility.<br><br>**Part 3: Device Design**<br>Structure and functionality of OFETs and OECTs; design challenges: contact formation, stability, and interaction with soft materials; integration of soft sensors into systems.<br><br>**Part 4: Challenges and Applications**<br>Scalability and production of soft electronics; environmental issues: recycling and lifespan of polymers; future applications and trends. |
| **Literature** | |

| Course L3197: Wearable Electronics: Materials and Applications | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Prof. Franziska Lissel |
| **Language** | EN |
| **Cycle** | SoSe |
| **Content** | In this module, you will learn the fundamentals of soft electronics and their application in innovative technologies such as wearables, health monitoring, and flexible displays. You will gain insight into the material properties of electrically conductive polymers and how to use them for flexible devices. Additionally, you will be introduced to the design principles of organic transistors (OFETs and OECTs) and explore the challenges in developing soft electronics. By the end of the module, you will be able to develop your own solutions for practical problems in this exciting field and reflect on the societal relevance of these technologies.<br><br>The module follows a Problem-Based Learning (PBL) format, where you will work in groups on a specific problem (e.g., a soft, stretchable sensor for health monitoring). In an asynchronous online seminar, you will receive feedback and guidance. At the end, you will present your results in a presentation, which also serves as the final exam.<br><br>**Overview Lecture: Wearable Electronics - Theoretical Foundations**<br><br>**Part 1: Introduction**<br>Overview of soft polymer electronics and their significance (wearables, health monitoring, flexible displays, robotics); introduction to organic electronics and the role of OFETs and OECTs. Introduction to the problem-based learning format.<br><br>**Part 2: Material Properties**<br>Electrically conductive polymers: properties, types, and processing; mechanical properties: elasticity, fracture strain, and criteria for selecting materials for flexible devices; trade-offs between conductivity and flexibility.<br><br>**Part 3: Device Design**<br>Structure and functionality of OFETs and OECTs; design challenges: contact formation, stability, and interaction with soft materials; integration of soft sensors into systems.<br><br>**Part 4: Challenges and Applications**<br>Scalability and production of soft electronics; environmental issues: recycling and lifespan of polymers; future applications and trends. |
| **Literature** | |

## Module M1796: Magnetic resonance in engineering

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Fundamentals of Magnetic Resonance (L2968) | Lecture | 3 | 3 |
| Magnetic Resonance in Engineering (L2969) | Project-/problem-based Learning | 3 | 3 |

| | |
|---|---|
| **Module Responsible** | Dr. Stefan Benders |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | No special previous knowledge is necessary. |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | This module covers the fundamentals of nuclear magnetic resonance spectroscopy (NMR) and magnetic resonance imaging (MRI) and their applications in engineering disciplines. The module consists of a classical lecture complemented by a problem-based learning course that includes practical hands-on experience on magnetic resonance devices. The module will be held in English. |
| *Skills* | After the successful completion of the course the students shall:<br>1. Understand the physical principles and practical aspects of magnetic resonance in engineering.<br>2. Know how to safely operate NMR and MRI systems.<br>3. Know how to run standard experimental sequences and how to implement more advanced sequence protocols.<br>4. Have an overview of the current capabilities and limits of the MR technique |
| **Personal Competence** | |
| *Social Competence* | In the problem-based course Magnetic Resonance in Engineering, the students will obtain hands-on experience on how to operate NMR spectrometers and high-field and low-field MRI systems. The course will cover safety aspects, pulse sequence design, spectral image analysis, and image reconstruction. The students will work in small groups on practical tasks on different NMR and MRI systems located at the campus of TUHH. |
| *Autonomy* | Through the practical character of the PBL course, the student shall improve their communication skills. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | None |
| **Examination** | Subject theoretical and practical work |
| **Examination duration and scale** | 120 Minutes |
| **Assignment for the Following Curricula** | Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation C - Bioeconomic Process Engineering, Focus Energy and Bioprocess Technology: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation General Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory<br>Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Artificial Organs and Regenerative Medicine: Elective Compulsory<br>Process Engineering: Specialisation Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Chemical Process Engineering: Elective Compulsory<br>Process Engineering: Specialisation Environmental Process Engineering: Elective Compulsory |

| Course L2968: Fundamentals of Magnetic Resonance | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Dr. Stefan Benders |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | This lecture covers the fundamentals magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (NMR). It focuses on the following topics:<br>1. The fundamentals of magnetic resonance: magnetism, magnetic fields, radiofrequency, spin, relaxation<br>2. Hardware for magnetic resonance: magnets (high-field and low-field), radiofrequency coil design, magnetic field gradients<br>3. NMR-Spectroscopy: chemical shift, J-Coupling, 2D NMR, solid-state, MAS<br>4. Relaxometry: single-sided NMR, contrasts,<br>5. Magnetic resonance imaging (MRI): gradients, coils, k-space, imaging sequences, ultrafast Imaging, parallel imaging, velocimetry, CEST<br>6. Hyperpolarization techniques: DNP, p-H2, optical pumping with Xe<br>7. Applications of magnetic resonance in chemical engineering<br>8. Applications of magnetic resonance in material science and engineering<br>9. Applications of magnetic resonance in biomedical engineering |
| **Literature** | Stapf, S., & Han, S. (2006). NMR imaging in chemical engineering. Weinheim: Wiley-VCH. ISBN: 978-3-527-60719-8<br>Blümich B., (2003) NMR imaging of materials. Oxford University Press, Online- ISBN: 9780191709524 , doi: https://doi.org/10.1093/acprof:oso/9780198526766.001.0001<br>Brown R. W., Cheng Y. N., Haacke E. M., Thompson M. R., Venkatesan R., (2014) Magnetic Resonance Imaging: Physical Principles and Sequence Design, Second Edition, John Wiley & Sons, Inc., doi: 10.1002/9781118633953<br>Haber-Pohlmeier, Sabina, Bernhard Blumich, and Luisa Ciobanu, (2022) Magnetic Resonance Microscopy: Instrumentation and Applications in Engineering, Life Science, and Energy Research. John Wiley & Sons |

| Course L2969: Magnetic Resonance in Engineering | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Dr. Stefan Benders |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | In this course, the theoretical basics of magnetic resonance spectroscopy and magnetic resonance tomography are supplemented with practical experiments on the respective devices. The practical handling and operation of the equipment will be learned. |
| **Literature** | Stapf, S., & Han, S. (2006). NMR imaging in chemical engineering. Weinheim: Wiley-VCH. ISBN: 978-3-527-60719-8<br>Blümich B., (2003) NMR imaging of materials. Oxford University Press, Online- ISBN: 9780191709524, doi: https://doi.org/10.1093/acprof:oso/9780198526766.001.0001<br>Brown R. W., Cheng Y. N., Haacke E. M., Thompson M. R., Venkatesan R., (2014) Magnetic Resonance Imaging: Physical Principles and Sequence Design, Second Edition, John Wiley & Sons, Inc., doi: 10.1002/9781118633953 |

## Module M1915: Materials Science Seminar

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Seminar (L1757) | Seminar | 2 | 3 |
| Seminar Composites (L1758) | Seminar | 2 | 3 |
| Seminar Advanced Ceramics (L1801) | Seminar | 2 | 3 |
| Seminar on interface-dominated materials (L1795) | Seminar | 2 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Jörg Weißmüller |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Fundamental knowledge on nanomaterials, electrochemistry, interface science, mechanics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain the most important facts and relationships of a specific topic from the field of materials science. |
| *Skills* | Students are able to compile a specified topic from the field of materials science and to give a clear, structured and comprehensible presentation of the subject. They can comply with a given duration of the presentation. They can write in English a summary including illustrations that contains the most important results, relationships and explanations of the subject. |
| **Personal Competence** | |
| *Social Competence* | Students are able to adapt their presentation with respect to content, detailedness, and presentation style to the composition and previous knowledge of the audience. They can answer questions from the audience in a curt and precise manner. |
| *Autonomy* | Students are able to autonomously carry out a literature research concerning a given topic. They can independently evaluate the material. They can self-reliantly decide which parts of the material should be included in the presentation. |
| **Workload in Hours** | Depends on choice of courses |
| **Credit points** | 3 |
| **Assignment for the Following Curricula** | Materials Science and Engineering: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science and Engineering: Specialisation Modeling: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Engineering Materials: Elective Compulsory<br>Materials Science: Specialisation Modeling: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Biomedical Engineering: Specialisation Implants and Endoprostheses: Elective Compulsory<br>Biomedical Engineering: Specialisation Medical Technology and Control Theory: Elective Compulsory<br>Biomedical Engineering: Specialisation Management and Business Administration: Elective Compulsory |

### Course L1757: Seminar

| | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Jörg Weißmüller, Prof. Shan Shi |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | Current topics of materials research in the field of metallic nanomaterials. |
| **Literature** | Ausgehend von aktuellen Fachpublikationen erarbeiten die Studierenden unter Anleitung die wissenschaftlichen Grundlagen und stellen dazu die jeweils relevanten Arbeiten aus der Fachliteratur zusammen.<br><br>Based on current scientific publications, and under guidance, students work out the scientific fundamentals and compile the relevant works from the professional literature in each case. |

| Course L1758: Seminar Composites | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Bodo Fiedler |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | Current topics in materials research in the field of polymers, their composites and nanomaterials. |
| **Literature** | Based on current scientific publications, and under guidance, students work out the scientific fundamentals and compile the relevant works from the professional literature in each case. |

| Course L1801: Seminar Advanced Ceramics | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Gerold Schneider, Prof. Kaline Pagnan Furlan |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | |
| **Literature** | |

| Course L1795: Seminar on interface-dominated materials | |
|---|---|
| **Typ** | Seminar |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Examination Form** | Referat |
| **Examination duration and scale** | 30 min |
| **Lecturer** | Prof. Patrick Huber |
| **Language** | DE/EN |
| **Cycle** | WiSe/SoSe |
| **Content** | |
| **Literature** | |

## Module M0644: Optoelectronics II - Quantum Optics

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Optoelectronics II: Quantum Optics (L0360) | Lecture | 2 | 3 |
| Optoelectronics II: Quantum Optics (Problem Solving Course) (L0362) | Recitation Section (small) | 1 | 1 |

| | |
|---|---|
| **Module Responsible** | Dr. Alexander Petrov |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic principles of electrodynamics, optics and quantum mechanics |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Students can explain the fundamental mathematical and physical relations of quantum optical phenomena such as absorption, stimulated and spontanous emission. They can describe material properties as well as technical solutions. They can give an overview on quantum optical components in technical applications. |
| *Skills* | Students can generate models and derive mathematical descriptions in relation to quantum optical phenomena and processes. They can derive approximative solutions and judge factors influential on the components' performance. |
| **Personal Competence** | |
| *Social Competence* | Students can jointly solve subject related problems in groups. They can present their results effectively within the framework of the problem solving course. |
| *Autonomy* | Students are capable to extract relevant information from the provided references and to relate this information to the content of the lecture. They can reflect their acquired level of expertise with the help of lecture accompanying measures such as exam typical exam questions. Students are able to connect their knowledge with that acquired from other lectures. |
| **Workload in Hours** | Independent Study Time 78, Study Time in Lecture 42 |
| **Credit points** | 4 |
| **Course achievement** | None |
| **Examination** | Written exam |
| **Examination duration and scale** | 60 minutes |
| **Assignment for the Following Curricula** | Electrical Engineering and Information Technology: Specialisation Nanoelectronics and Microsystems Technology: Elective Compulsory<br>Electrical Engineering and Information Technology: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory<br>Electrical Engineering: Specialisation Microwave Engineering, Optics, and Electromagnetic Compatibility: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Microelectronics and Microsystems: Specialisation Microelectronics Complements: Elective Compulsory |

| Course L0360: Optoelectronics II: Quantum Optics | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 62, Study Time in Lecture 28 |
| **Lecturer** | Dr. Alexander Petrov |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | • Generation of light<br>• Photons<br>• Thermal and nonthermal light<br>• Laser amplifier<br>• Noise<br>• Optical resonators<br>• Spectral properties of laser light<br>• CW-lasers (gas, solid state, semiconductor)<br>• Pulsed lasers |
| **Literature** | Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, Wiley 2007<br>Demtröder, W., Laser Spectroscopy: Basic Concepts and Instrumentation, Springer, 2002<br>Kasap, S.O., Optoelectronics and Photonics: Principles and Practices, Prentice Hall, 2001<br>Yariv, A., Quantum Electronics, Wiley, 1988<br>Wilson, J., Hawkes, J., Optoelectronics: An Introduction, Prentice Hall, 1997, ISBN: 013103961X<br>Siegman, A.E., Lasers, University Science Books, 1986 |

| Course L0362: Optoelectronics II: Quantum Optics (Problem Solving Course) | |
|---|---|
| **Typ** | Recitation Section (small) |
| **Hrs/wk** | 1 |
| **CP** | 1 |
| **Workload in Hours** | Independent Study Time 16, Study Time in Lecture 14 |
| **Lecturer** | Dr. Alexander Petrov |
| **Language** | EN |
| **Cycle** | WiSe |
| **Content** | see lecture Optoelectronics 1 - Wave Optics |
| **Literature** | see lecture Optoelectronics 1 - Wave Optics |

## Module M0519: Particle Technology and Solid Matter Process Technology

**Courses**

| Title | Typ | Hrs/wk | CP |
|---|---|---|---|
| Advanced Particle Technology II (L0051) | Project-/problem-based Learning | 1 | 1 |
| Advanced Particle Technology II (L0050) | Lecture | 2 | 2 |
| Experimental Course Particle Technology (L0430) | Practical Course | 3 | 3 |

| | |
|---|---|
| **Module Responsible** | Prof. Stefan Heinrich |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | Basic knowledge of solids processes and particle technology |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | After completion of the module the students will be able to describe and explain processes for solids processing in detail based on microprocesses on the particle level. |
| *Skills* | Students are able to choose process steps and apparatuses for the focused treatment of solids depending on the specific characteristics. They furthermore are able to adapt these processes and to simulate them. |
| **Personal Competence** | |
| *Social Competence* | Students are able to present results from small teamwork projects in an oral presentation and to discuss their knowledge with scientific researchers. |
| *Autonomy* | Students are able to analyze and solve problems regarding solid particles independently or in small groups. |
| **Workload in Hours** | Independent Study Time 96, Study Time in Lecture 84 |
| **Credit points** | 6 |
| **Course achievement** | **Compulsory**: Yes; **Bonus**: None; **Form**: Written elaboration; **Description**: fünf Berichte (pro Versuch ein Bericht) à 5-10 Seiten |
| **Examination** | Written exam |
| **Examination duration and scale** | 120 minutes |
| **Assignment for the Following Curricula** | Bioprocess Engineering: Specialisation B - Industrial Bioprocess Engineering: Elective Compulsory<br>Bioprocess Engineering: Specialisation A - General Bioprocess Engineering: Elective Compulsory<br>Chemical and Bioprocess Engineering: Core Qualification: Elective Compulsory<br>Chemical and Bioprocess Engineering: Specialisation Chemical and Bioprocess Engineering: Elective Compulsory<br>International Management and Engineering: Specialisation II. Process Engineering and Biotechnology: Elective Compulsory<br>Materials Science and Engineering: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Materials Science: Specialisation Nano and Hybrid Materials: Elective Compulsory<br>Process Engineering: Core Qualification: Compulsory |

### Course L0051: Advanced Particle Technology II

| | |
|---|---|
| **Typ** | Project-/problem-based Learning |
| **Hrs/wk** | 1 |
| **CP** | 1 |
| **Workload in Hours** | Independent Study Time 16, Study Time in Lecture 14 |
| **Lecturer** | Prof. Stefan Heinrich |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | See interlocking course |
| **Literature** | See interlocking course |

| Course L0050: Advanced Particle Technology II | |
|---|---|
| **Typ** | Lecture |
| **Hrs/wk** | 2 |
| **CP** | 2 |
| **Workload in Hours** | Independent Study Time 32, Study Time in Lecture 28 |
| **Lecturer** | Prof. Stefan Heinrich |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | • Exercise in form of "Project based Learning"<br>• Agglomeration, particle size enlargement<br>• advanced particle size reduction<br>• Advanced theorie of fluid/particle flows<br>• CFD-methods for the simulation of disperse fluid/solid flows, Euler/Euler methids, Descrete Particle Modeling<br>• Treatment of simulation problems with distributed properties, solution of population balances |
| **Literature** | Schubert, H.; Heidenreich, E.; Liepe, F.; Neeße, T.: Mechanische Verfahrenstechnik. Deutscher Verlag für die Grundstoffindustrie, Leipzig, 1990.<br><br>Stieß, M.: Mechanische Verfahrenstechnik I und II. Springer Verlag, Berlin, 1992. |

| Course L0430: Experimental Course Particle Technology | |
|---|---|
| **Typ** | Practical Course |
| **Hrs/wk** | 3 |
| **CP** | 3 |
| **Workload in Hours** | Independent Study Time 48, Study Time in Lecture 42 |
| **Lecturer** | Prof. Stefan Heinrich |
| **Language** | DE/EN |
| **Cycle** | WiSe |
| **Content** | • Fluidization<br>• Agglomeration<br>• Granulation<br>• Drying<br>• Determination of mechanical properties of agglomerats |
| **Literature** | Schubert, H.; Heidenreich, E.; Liepe, F.; Neeße, T.: Mechanische Verfahrenstechnik. Deutscher Verlag für die Grundstoffindustrie, Leipzig, 1990.<br><br>Stieß, M.: Mechanische Verfahrenstechnik I und II. Springer Verlag, Berlin, 1992. |

# Thesis

## Module M1801: Master thesis (dual study program)

| Courses | | | |
|---|---|---|---|
| **Title** | **Typ** | **Hrs/wk** | **CP** |

| | |
|---|---|
| **Module Responsible** | Professoren der TUHH |
| **Admission Requirements** | None |
| **Recommended Previous Knowledge** | |
| **Educational Objectives** | After taking part successfully, students have reached the following learning results |
| **Professional Competence** | |
| *Knowledge* | Dual students ...<br>• ... use the specialised knowledge (facts, theories and methods) from their field of study and the acquired professional knowledge confidently to deal with technical and practical professional issues.<br>• ... can explain the relevant approaches and terminologies in depth in one or more of their subject's specialist areas, describe current developments and take a critical stance.<br>• ... formulate their own research assignment to tackle a professional problem and contextualise it within their subject area. They ascertain the current state of research and critically assess it. |
| *Skills* | Dual students ...<br>• ... can select suitable methods for the respective subject-related professional problem, apply them and develop them further as required.<br>• ... assess knowledge and methods acquired during their studies (including practical phases) and apply their expertise to complex and/or incompletely defined problems in a solution- and application-oriented manner.<br>• ... acquire new academic knowledge in their subject area and critically evaluate it. |
| **Personal Competence** | |
| *Social Competence* | Dual students ...<br>• ... can present a professional problem in the form of an academic question in a structured, comprehensible and factually correct manner, both in writing and orally, for a specialist audience and for professional stakeholders.<br>• ... answer questions as part of a professional discussion in an expert, appropriate manner. They represent their own points of view and assessments convincingly. |
| *Autonomy* | Dual students ...<br>• ... can structure their own project into work packages, work through them at an academic level and reflect on them with regard to feasible courses of action for professional practice.<br>• ... work in-depth in a partially unknown area within the discipline and acquire the information required to do so.<br>• ... apply the techniques of academic work comprehensively in their own research work when dealing with an operational problem and question. |
| **Workload in Hours** | Independent Study Time 900, Study Time in Lecture 0 |
| **Credit points** | 30 |
| **Course achievement** | None |
| **Examination** | Thesis |
| **Examination duration and scale** | According to General Regulations |
| **Assignment for the Following Curricula** | Civil Engineering: Thesis: Compulsory<br>Bioprocess Engineering: Thesis: Compulsory<br>Chemical and Bioprocess Engineering: Thesis: Compulsory<br>Chemical and Bioprocess Engineering: Thesis: Compulsory<br>Computational Engineering: Thesis: Compulsory<br>Computer Science: Thesis: Compulsory<br>Data Science: Thesis: Compulsory<br>Electrical Engineering and Information Technology: Thesis: Compulsory<br>Electrical Engineering: Thesis: Compulsory<br>Energy Systems: Thesis: Compulsory<br>Environmental Engineering: Thesis: Compulsory<br>Aircraft Systems Engineering: Thesis: Compulsory<br>Computer Science in Engineering: Thesis: Compulsory<br>Information and Communication Systems: Thesis: Compulsory<br>International Management and Engineering: Thesis: Compulsory<br>Logistics, Infrastructure and Mobility: Thesis: Compulsory<br>Aeronautics: Thesis: Compulsory<br>Mechanical Engineering - Product Development and Production: Thesis: Compulsory<br>Materials Science and Engineering: Thesis: Compulsory<br>Materials Science: Thesis: Compulsory |

| | |
|---|---|
| | Mechanical Engineering and Management: Thesis: Compulsory<br>Mechatronics: Thesis: Compulsory<br>Biomedical Engineering: Thesis: Compulsory<br>Microelectronics and Microsystems: Thesis: Compulsory<br>Product Development, Materials and Production: Thesis: Compulsory<br>Renewable Energies: Thesis: Compulsory<br>Naval Architecture and Ocean Engineering: Thesis: Compulsory<br>Naval Architecture and Ocean Engineering: Thesis: Compulsory<br>Theoretical Mechanical Engineering: Thesis: Compulsory<br>Process Engineering: Thesis: Compulsory<br>Water and Environmental Engineering: Thesis: Compulsory |