Temaområde: Biomekanikk, nanomekanikk, og nye materialer

Målet er å utdanne handlekraftige og omstillingsdyktige kandidater som kan løse dagens og særlig fremtidens utfordringer med fokus på innovative og bærekraftige løsninger som sikrer fremtiden i vårt teknologiske samfunn. Fellesnevner for vårt temaområde er industriell eller anvendt mekanikk, som omfatter både konstruksjons- og strømningsrelaterte problemområder. Vår forskning er hovedsaklig knyttet til numerisk simulering, fenomenologisk og probabilistisk materialmodellering samt eksperimentell og full-skala testing på alt fra nano til full-skala nivå.

Vitenskapelige ansatte innen vårt temaområde er:

- 7 fast vitenskapelige ansatte: Jianying He, Leif Rune Hellevik, Victorien Prot, Bjørn Skallerud, Marius Solberg, Senbo Xiao og Zhiliang Zhang.
- 2 professor II (20% deltidsstilling): Helge Kristiansen (hovedstilling i Conpart ASA) og en chair professor Gerhard Holzapfel fra Graz University of Technology, Østerike.
- Ca 25 PhD/post.doc.

Forskningsfeltene er:

- **Biomekanikk** (Bjørn Skallerud, Leif Rune Hellevik, Victorien Prot). Forskningsfeltet innen gruppen er modellering og analyse av biologiske systemer, med spesielt fokus på hjertekar-anvendelser (hjertevegg, klaffer, blodkar og blodstrøm). Vårt mål er å utvikle numeriske modeller og metoder som kan benyttes for å forstå de naturlige funksjoner av disse strukturene og virkningene av sykdommer og hjelpe klinikere å forbedre diagnose og kirurgiske prosedyrer. Andre forskningsområder i vår gruppe er: beinmekanikk, levering av legemidler og modellering av hydrogeler og biologiske tynne filmer.

- **Nanomekanikk og nye materialer** [https://www.ntnu.edu/nml] (Jianying He, Zhiliang Zhang, Marius Solberg, Senbo Xiao): Our new research group currently has more than 16 PhD students and post docs studying on many exciting and industry and society relevant problems. Typical research questions are how to develop novel metal deposition patterns for additive manufacturing technology with the purpose to minimize the resulting residual stresses and enhance the structural integrity; how to apply the machine learning technique to understand the role of surface roughness on ice adhesion strength; how to design and develop world's toughest polymer materials for flexible electronics applications; how to implement the emerging data-driven and material model-free strategy to the conventional finite element method, et al. Some of our research are truly world leading. If you are interested in some of the topics for your project and master study, please visit: https://www.ntnu.edu/nml/project/master-thesis-topics .

- **Bruddmekanikk og utmatting** (Bjørn Skallerud og Zhiliang Zhang): Forskningsfeltet bruddmekanikk og utmatting studerer oppførsel av metalliske eller sveiste komponenter og konstruksjoner med og uten sprekk påkjent av statisk og syklisk last. Vårt mål er å forstå materials degraderings-mekanismer på mikroskala slik at vi kan utvikle og forbedre industrielt relevante metoder for levetids- og konstruksjons integritets-beregninger. Vi har et nært samarbeide med SINTEF og andre industriselskaper for å få oppdatert prosjekt og masteroppgaver.

Prosjekt- og masteroppgave innen vårt temaområde kan velges av studenter fra studieretningene:

- Konstruksjon (MTBYGG, MIBYGG)
- IKT og Konstruksjonsteknikk (MTING)
- Industriell mekanikk (MTPROD, MIPROD)

Prosjektoppgave i høstsemesteret 2023:

Målsettingen med dette prosjektet er at studentene skal lære seg eksperimentelle, numeriske og analytiske metoder for analyse av ikke-lineær respons av konstruksjoner. Det legges vekt på at studentene skal få praktisk erfaring med bruk av numeriske verktøy (ABAQUS) og relevant laboratorieerfaring. Oppgaven inneholder vanligvis følgende tre deler:

- Material- og komponenttester i laboratoriet
- Modellering og numeriske simuleringer med ABAQUS
- Analytiske beregninger

Koblingen mellom de eksperimentelle og de beregningsmessige delene av prosjektet er viktig av to årsaker. For det første vil eksperimentene gi informasjon om fysikken i problemet, noe som i neste runde påvirker den analytiske eller numeriske beregningsmodellen. For det andre er separate materialforsøk påkrevet for å fremskaffe data for materialets oppførsel.

Prosjektet gir et godt grunnlag for en masteroppgave innenfor fagområdet som dekkes av temaområdet «Biomekanikk, nanomekanikk og nye materialer», og studentene får materialmekanikk- og elementmetode-kompetanse som er etterspurt i arbeidsmarkedet.

Masteroppgave i vårsemesteret 2024

I masteroppgaven vil studentene bli tilknyttet de løpende forskningsprosjektene i de tre forskningsfeltene som ble nevnt på forrige side (Biomekanikk, Nanomekanikk og nye materialer, Bruddmekanikk og utmatting). Oversikten nedenfor viser noen av masteroppgavene som kan være aktuelle i 2023-2024.

Informasjonsmøte 2023

Vi inviterer til et informasjonsmøte tirsdag 23. april kl 11:15 – 12:15 i Holand and på Zoom.

Holand meeting room: https://link.mazemap.com/nsoUEgfV
Zoom link: https://NTNU.zoom.us/j/91721308994?pwd=YWtLNTZxTUc5Ry9LSkJIVXBSd29hZz09

Biomekanikk

General Information about the Biomechanics division at NTNU can be found here:
https://www.ntnu.edu/biomechanics .
The topics described below are eligible for both specialization projects and Master's theses.

1. Biomechanics of the heart for treatment of late injuries after myocardial infarction

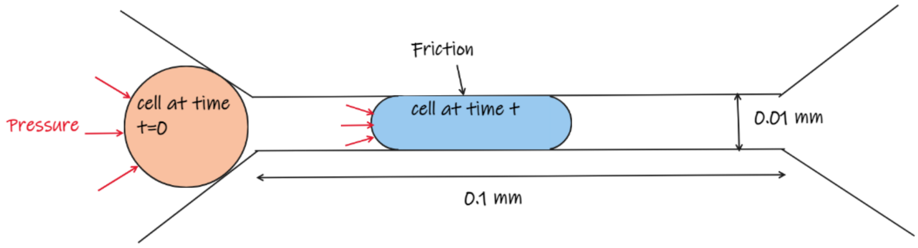
Each year, about 11,000 myocardial infarctions are registered in Norway. About a third develop a valve leakage in the heart afterwards. This means that some of the blood, that should flow into the body with oxygen, flows back to the lungs through a leaky heart valve. When such a leakage becomes large it can lead to shortness of breath, and in the worst-case death.
Now, we are researching (with the Department of Heart Disease at Haukeland) why some of the patients after successful treatment of acute heart attack develop such a valve leakage in the left heart chamber. Our aim is to be able to better adapt the treatment to each patient (personalized medicine). To this end, we create numerical models of patients' hearts from medical images and simulate different valve repair procedures to find out which one works best.
See also our story on tv2.no.
Relevant interests, competencies, and methods: Numerical methods, Finite Element method, non-linear elasticity, programming.
Contact: Victorien Prot, victorien.prot@ntnu.no

2. Mechanical characterization of biological tissues

We are involved in several different activities that need good and representative mathematical material models for soft tissue. Two relevant activities are "Modeling of soft tissue in the upper airways" and "modeling of lymph nodes and lung tissue (healthy and cancerous)". The first relates to a large project on obstructive sleep apnea, in collaboration with CFD and ear-nose-throat surgeons. The second relates to collaboration with the Lung clinic at St Olavs hospital. For both, to improve diagnosis tools and treatments, modeling of the soft tissues is important. In this project, the students will get access to biological tissue, carry out mechanical testing in the biaxial test machine and fit mathematical models and corresponding model parameters to the test results.
Relevant interests, competencies, and methods: Numerical methods, Finite Element method, non-linear elasticity, mechanical testing.
Contact: Prof Bjørn Skallerud, bjorn.skallerud@ntnu.no

3. Fast and efficient mechanical characterization of cancer cells

Using cell deformation analysis, cancer cells can be found and sorted from healthy cells in a sample. For several cell types, it has been reported that malignant cells are less stiff than their normal counterparts. Atomic force microscopy (indentation), micro pipette aspiration are examples of the common approaches which provide detailed information of the mechanical properties of the cell. However, they are time consuming, and thus, challenging to use for efficient characterization of a high number of cells. Microfluidic devices are being developed at NTNU to improve the efficacy of cell's mechanical characterization. The main goal of this devices is to discriminate malignant cells from normal cells based on their mechanical properties in a very short amount of time, and therefore, improve cancer diagnosis.
One approach for such devices is to force cells through constrictions smaller than their cross-section. This has the potential to provide distributions of mechanical properties over the cells being characterized.



These microfluidic devices need to be modelled and calibrated before proceeding to more general use. Issues that should be addressed in the computational modelling is the description of the stress/ deformation fields imposed with respect to the operating conditions of the device and the mechanical properties of the cells.

<u>Relevant interests, competencies, and methods:</u> Finite Element Method or/and Computational Fluid Dynamics, non-linear elasticity, programming.

<u>Contact</u>: Victorien Prot, victorien.prot@ntnu.no

4. Personalized mechanical modeling for cardiovascular medicine

Numerous diseases and conditions like heart failure, diabetes, kidney failure, sepsis and hypertension involve multiple organ systems and physicians thus face a complex task to determine what care will be effective for any given individual. The cardiovascular system plays a fundamental role in the function of all organs, and thus personalized modeling of the cardiovascular system can assist in providing an integrated understanding of how dysfunctions in particular organs or blood vessels may result in problems for other tissues; for example, the weakening of the heart in heart failure may cause blood and fluid to accumulate in the legs. For heart failure and hypertension, several drugs targeting the heart, blood vessels and the kidneys are commonly prescribed, and despite extensive efforts it is often uncertain whether a particular drug will have the desired effect in each individual. Personalized biomechanical modeling can be used to predict how localized effects of treatments cause changes in the blood pressures and flows throughout the body and thus influence the function of other organ systems, which may allow physicians to choose treatment strategies more optimally.

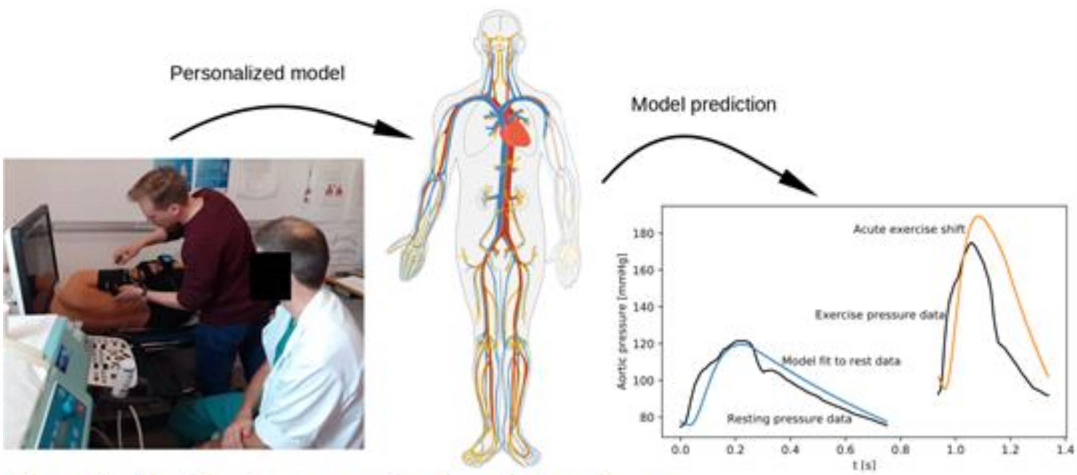


Figure 1: Pipeline for personalized model predictions

To enable such personalized modeling, methods for determining personalized model parameters from clinical data must be developed and models of both the fluid and solid mechanics of the heart and blood vessels must be further improved. Additionally, the influence of physiological regulatory mechanisms must be coupled with the fundamental models of blood flow and pressure.

Our current research efforts are applying state of the art computational mechanics, statistics, machine learning, and physiology to investigate:

1. How does the cardiovascular system change for a given amount habitual exercise?
2. How can the blood pressure at easily measured locations (the finger) be connected to the pressure at inaccessible locations (the heart and central arteries)?

3. Can we model how the blood pressure and flow transition during exercise such as running?
4. Ultrasound imaging allows us to see the heart and arteries. Can we develop a pipeline to infer personal mechanical properties by connecting these images to mechanical models?
5. What mechanical properties change for different hypertension treatments and when are these expected to effectively reduce blood pressure?
6. Can changes in the efficiency of the coupling of the heart and arteries predict what support is needed in patients in surgery or recovering from surgery?

See also: https://ntnu.edu/biomechanics/enthral ntnu.no/cerg/mymdt and

Possible competencies and subjects of focus: Numerical methods, fluid mechanics, fluid-structure interactions, solid mechanics, simulation, mathematical modeling, physiology, exercise, statistics, uncertainty quantification, machine learning.

Contacts: Prof Leif Rune Hellevik, leif.r.hellevik@ntnu.no.

3. Personalized modeling for diagnosis of heart disease

Coronary artery disease is the build-up of plaque in the arteries supplying the heart with blood. Large plaques or the rupture of a plaque into pieces may lead to a reduction in the blood flow to the muscles of the heart and cause a heart attack (myocardial infarction). Historically, the most common treatment of coronary artery disease has been through a surgery where the plaque is removed (pushed into the artery wall) and a metallic stent is placed over the region. However, recent research shows that the benefit of such a surgery depends on the severity of the plaque build-up, and that treatment through medication and physical exercise is more beneficial in many cases. The current procedure to assess the severity of plaque build-up this is based primarily on medical imaging or in some cases a small surgery/test is performed to measure the pressure/flow in the blocked artery. Diagnosis based on personalized simulation of the blood flow in these arteries would be preferable to both approaches as it accounts for the mechanics (in contrast to imaging) and avoids unnecessary surgery and associated risks.

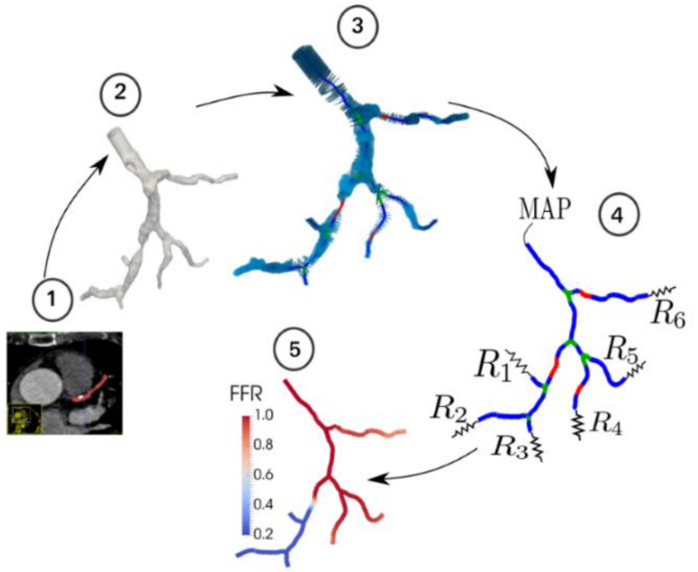


Figure 2Modeling pipeline to diagnose coronary artery disease from medical imaging

A project is currently underway to implement personalized coronary blood flow simulations for coronary artery disease diagnosis, ntnu.edu/health/model-based-noninvasive-diagnosis-of-coronary-artery-disease-with-3d-ultrasound-and-ct

Challenges within this project include:

1. Full CFD simulations are too computationally expensive for real-time clinical application. Can reduced order modeling combine physics and machine learning to enable fast and accurate computation?

2. There are numerous methods for performing CFD based on finite elements, finite volume, or reduced order approaches. Which methods are most suitable to routine clinical application?
3. Medical decisions must account for uncertainty about the input data. Can we quantify how the uncertainties in measurements and data processing affect the model's predictions?
4. While acquiring images of the arteries is easy, their geometry must be extracted from the images before simulations can be performed. Can we automate this process?

Relevant interests, competencies, and methods: Numerical methods, fluid mechanics, fluid-structure interactions, solid mechanics, image segmentation, mathematical modeling, physiology, exercise, statistics, uncertainty quantification, machine learning
Contacts: Prof Leif Rune Hellevik, leif.r.hellevik@ntnu.no.

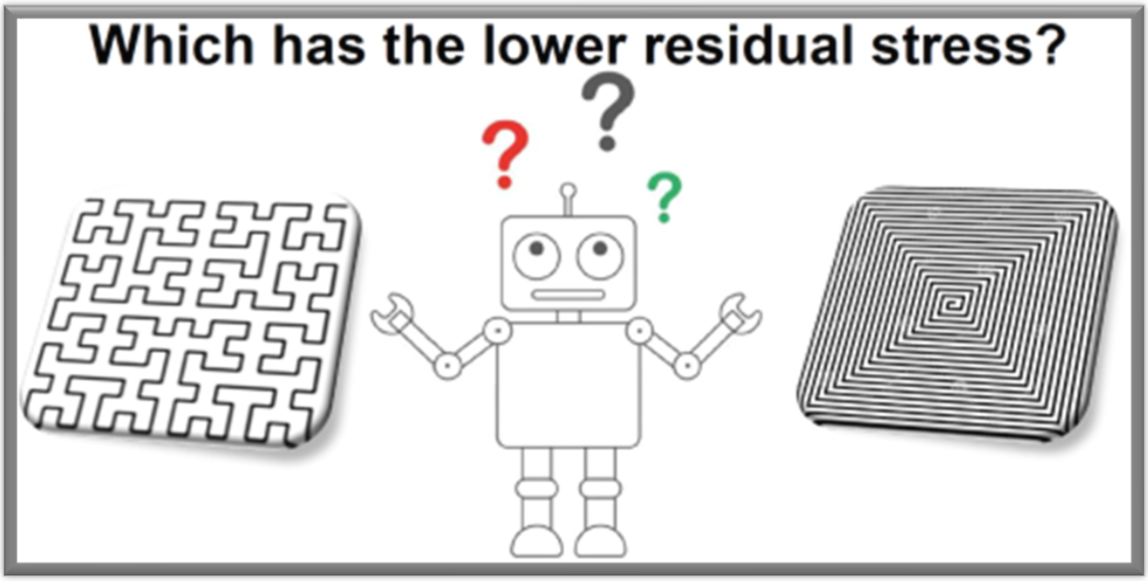
Prosjekt- og masteroppgaver i nanomekanikk og nye materialer 2023/2024:

Here we list some of the project/master study topics. For a general overview of NTNU Nanomechanical Lab, please visit https://www.ntnu.edu/nml. For a detailed overview of the available topics which are linked to the ongoing research projects in the group, please visit our group homepage: https://www.ntnu.edu/nml/project/master-thesis-topics

1. Digital Twin of Metal Additive Manufacturing for Sustainability

Effective manufacturing is of undeniable importance both nationally and internationally. Additive Manufacturing (AM) is regarded as **a key enabling technology** with the potential of 3D printing any material, any shape and in any fields, without the need for specialized tooling. Considering its great application potentials such as locally making spare parts based on demand and as a chief repairing repair and refurbishment tool for aging structures, AM can play a vital role in todays sustainability. However, large quality variance, poor process consistency and lack of predictability of properties and performance of printed parts are hindering the wide spreading of the promising technology. There is an urgent need to develop a **digital platform** which can be used to optimize the AM process parameters based on the predicted properties and performance **in real time**. The objective of the project/master study is to develop ABAQUS simulation based digital platform for residual stress elimination/minimization/prediction, distortion control and mitigation of additively manufactured components. We can define specific tasks tailored made for students' background and interest. For more details see the above link to our home page.

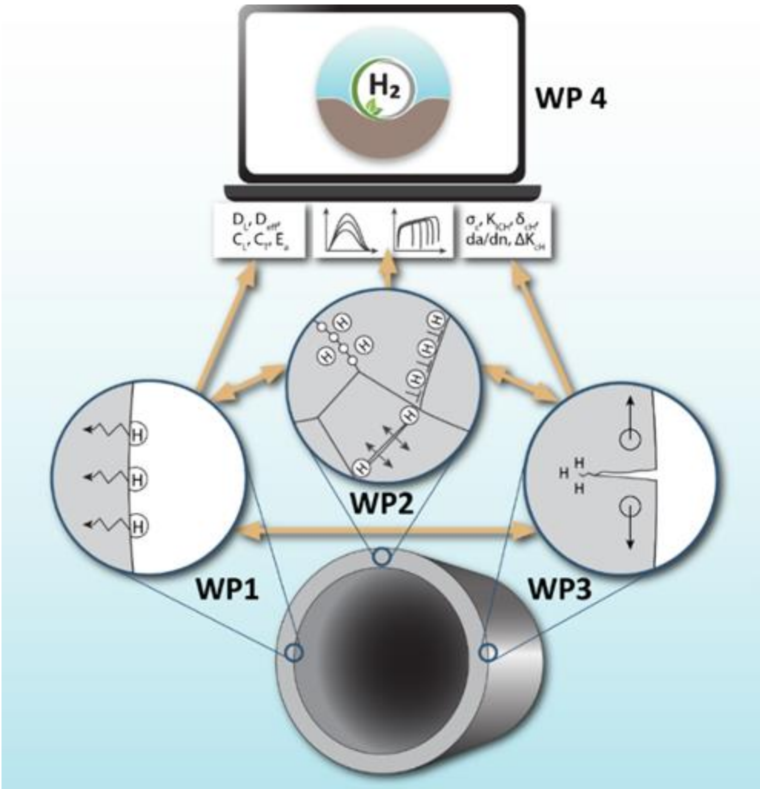
Contact: Prof. Zhiliang Zhang zhiliang.zhang@ntnu.no, Prof. Kjell Magne Mathisen kjell.mathisen@ntnu.no.



2. Structural integrity analysis and life extension of hydrogen energy infrastructure

Hydrogen is a priority area in the European Green Deal. Hydrogen plays a vital role in the inevitable and needed transition from fossil fuels to renewable energy. Being a major energy provider in Europe, Norway has the obligation to be a main player in this transition. A safe and efficient use of Norway's vast subsea pipeline network for transporting hydrogen to the market will be a strong driving force for this transition to happen. One downside of the hydrogen technology is the premature failure of the metallic infrastructure induced by the hydrogen. The project/master thesis will a part of the ongoing large-scale research project **Safe Pipelines for Hydrogen Transport (HyLINE)** led by SINTEF. The specific task of the project/master study is to work together with the PhD students to develop appropriate finite element models which can describe and predict the safety of hydrogen transport system using ABAQUS. Best would be 2 students working together.

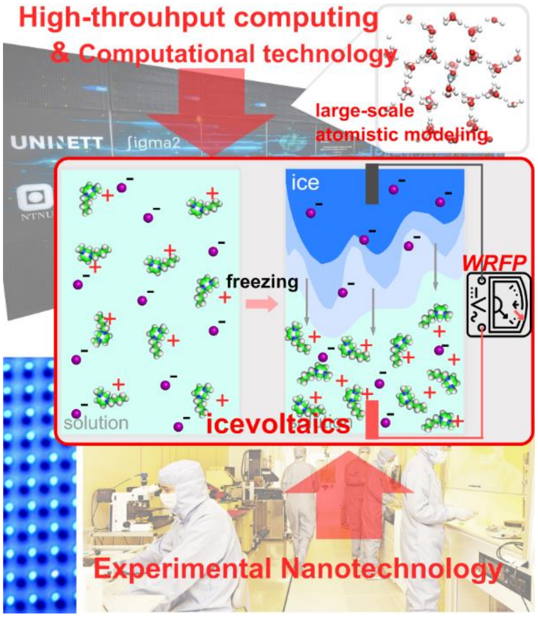
For details, contact: Prof. Zhiliang Zhang, zhiliang.zhang@ntnu.no.



3. Project topic under the Icevoltaics ERC grant

Water and aqueous solutions release a huge amount of thermal energy during freezing. Specifically, freezing of 1 kg water releases the amount of energy equals to the kinetic energy of 1 kg water falling from a water dam of 32 km in height. Accessing energy utilizing the freezing process has never been attempted until today.

The **icevoltaics** project combines high-throughput computing and nanotechnological methodologies to the focus of recovering energy in the freezing process of aqueous solutions. The aim is to explore the mechanism of energy release and harvesting using ice growth in water solution. The project will seed a new green energy research area and pave the avenue of energy recovery driven by seasonal natural cooling.



The topics for master thesis include but not limit to literature review, modeling and experiments on:

- Icing physics
- Atomistic fundamentals of icing interface
- Icing thermal energy harvesting
- Interface design for ice nucleation
- Icing control in solution
- Anti-icing
- Ice adhesion
- Others related to icing.

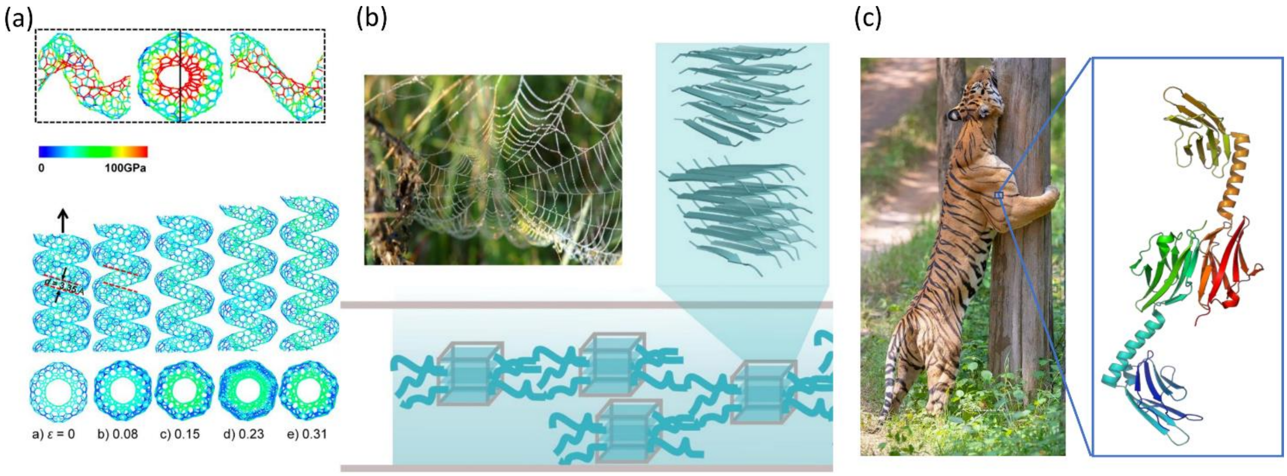
Contact: Senbo.xiao@ntnu.no

4. Molecular mechanics: mechanical stability of molecular structures

The mechanical stability of molecular structures is the basis of materials properties. For example, highly stiff hierarchical structure of chemical bonds enables giant stretchability and reversibility in helical carbon nanotubes; clusters of ordered hydrogen bonds results in robust nano-crystalline polymer structures and further tough spider-silk fibers; special molecular connections lead to the great adaptability of muscles under different load conditions (see examples in the following figure). This study topic will focus on using atomistic modeling to rebuild molecular structures in computer, employing molecular dynamics simulations to apply load onto the molecular structures, and further accessing the mechanical properties of the molecular structures, with the aim of understanding the possible functions of molecular structures under mechanical load. The specific steps of the projects include:

1) Choosing molecular structures of interests based on literature review (0.5 ~ 1 month).
2) Modeling of the molecular structure using atomic interaction potentials (1 ~ 2 month).
3) Performing molecular dynamics simulations (2 ~ 3 months).
4) Results collection, data analysis and report drafting (master thesis) (1~2 months).

Contact: Assoc. Prof. Senbo Xiao, senbo.xiao@ntnu.no



5. Tailoring adhesion in paint

To tailor surfaces for specific applications and/or to protect them from corrosion, fouling, weathering deterioration, etc. organic coatings are applied to the surface. A critical parameter to consider for a coating is the adhesion properties of the film, both to the substrate and between the different layers of the paint film. When the substrate to be coated is a metal, adhesion of the coating to it is referred to as direct-to-metal adhesion. In most commercially important cases, multiple layers of organic coatings are applied on a metallic substrate and in such cases inter-layer adhesion also plays a crucial role in determining the performance of the whole coating system. Therefore, direct-to-metal adhesion and inter-layer adhesion are both commercially relevant but involve different interfacial mechanisms of adhesion. Adhesion of coatings is a complex phenomenon depending on surface free energy, chemical bonds, surface roughness, cleanliness, mechanical strength, and application conditions, etc. The project and master thesis work will contribute to understanding the coating adhesion and hence optimizing the coating design by integrating advanced computational simulation and pathbreaking experiment. The master students will collaborate with one PhD and one postdoc researcher at NTNU Nanomechanical Lab, as well as researchers at Jotun AS.

- Experimental characterization of mechanical adhesion (2 students)
- Finite element analysis of coating adhesion property in Abaqus (1-2 students)
- Atomistic and molecular origin of adhesion for improved coating design by molecular dynamic simulation (2 students)

Contact: Prof. Jianying He, jianying.he@ntnu.no.

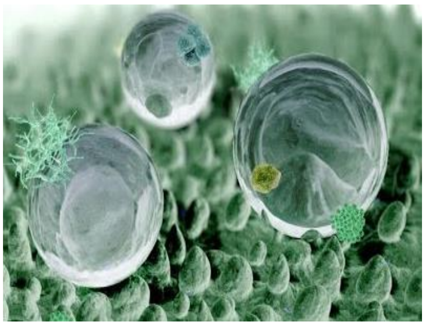
6. Nature-inspired water and ice-repelling nanostructured surfaces

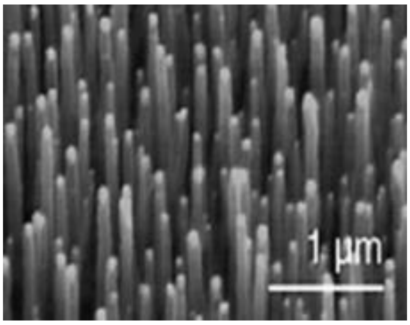
Recently, many nanofabricated surfaces with unique physical and chemical properties like super sticky, self-cleaning, hydrophilic, hydrophobic, ice-phobic, anti-fouling properties and with their combinations (multi-purpose smart surfaces) have been elaborated. Many important physical and geometric principles of their structure and function can be taken from nature, for instance self-cleaning lotus leaf, super sticky glue from mussels, super-hydrophobic surfaces of insects, air-accumulating surfaces of some leaves and water insects, ice-phobic insect eyes and many others. Modern water and ice-repelling surfaces must sustain different ambient conditions (temperature, pressure, humidity, wind), that needs elaboration of smart nanostructures of different materials.

In this project, the student will familiarize with irreversible thermodynamics at the microscale and learn how the surface geometry and physical parameters influence its water- and ice-repelling abilities. The project will be carried out according to the following steps:

1. Classification of the nanostructured natural surfaces discovered in plants and animals and studied in literature.
2. Discussion of the physical and chemical mechanisms of the “smartness”.
3. Elaboration of simplifies models of the nanostructured natural surfaces and computations of their surface energy.
4. Comparative analysis of their smart properties and propositions for experimental verification of theoretical results and discussion of possible application.

Contact: Prof. Jianying He jianying.he@ntnu.no.





7. Detection of Lie subalgebras.

This is a description of a possible master's degree project at the Department of Structural Engineering, with Marius Solberg as supervisor. The aim of the project is writing a code that detects so-called Lie subalgebras, which are important for theoretical physics. The project could be suitable for a student who likes, and is good at linear algebra and programming. The student must be interested in working with a purely theoretical topic, and want to learn some advanced mathematics that can be applied in theoretical physics.

1 Matrices and Lie algebras

A *Lie algebra* is a vector space V consisting of square matrices, with an additional operation called the *commutator* of any $X, Y \in V$. The commutator is given by $[X, Y] = XY - YX \in V$, and the commutator must thus itself be contained in V. The term Lie algebra is named after the Norwegian mathematician Sophus Lie (1842-1899).

In this project, we will concentrate on the Lie algebra called $\mathfrak{su}(N)$. Physicists define this Lie algebra as the set of all *Hermitian* $N \times N$ matrices without *trace*. Hermitian here means that a combination of transposition and complex conjugation returns the matrix you started with, $(X^T)^* = X$. The matrices having no trace means that the sum of the diagonal elements is equal to zero. A *subalgebra* of $\mathfrak{su}(N)$ will then be a subset $\mathfrak{h}$ of $\mathfrak{su}(N)$ which itself is a Lie algebra.

2 Higg particles and detection of subalgebras of $\mathfrak{su}(N)$

The Higgs particle was postulated by, among others, the Scotsman Peter Higgs in 1964, and discovered at CERN in 2012. The problem this master's degree project deals with arises in particle physics models with more than one Higgs particle. Models involving more Higgs particles than the one already discovered can, among other things, explain the observed asymmetry between matter and antimatter in the universe. The mathematical expression (a fourth degree polynomial) that describes the Higgs particles' masses and interactions with themselves, the *Higgs potential*, contains a $(N^2 - 1) \times (N^2 - 1)$ matrix Λ, where the number of new Higgs particles introduced increases by N. When $N = 1$ we only have the Higgs particle observed at CERN. It turns out that the eigenvectors of this matrix are important for the properties of the potential it describes. If, for example, there are $k \equiv N(N-1)/2$ eigenvectors which, through a certain mechanism, generate the subalgebra of $\mathfrak{su}(N)$ called $\mathfrak{so}(N)$, then the potential, if it fulfills some simple additional conditions, will have *CP2-symmetry*. The latter means, among other things, that the potential is restricted in describing the aforementioned asymmetry between matter and antimatter.

My PhD student Robin Plantey has written a Mathematica program that determines whether $k = N(N-1)/2$ eigenvectors of Λ give a subalgebra of $\mathfrak{su}(N)$. The main task in this master's degree project is to generalize this computer program, preferably in the mathematical programming language Mathematica, so that it can detect a subalgebra of any size $l < N^2 - 1$.

Hence the master's project will consist of the following steps:

1. Describe the mathematical basis for detection of Lie subalgebras (matrices, eigenvectors, Lie algebras).
2. Give a brief popular scientific introduction to how these algebras are relevant to physics. The student decides for himself how deeply he wants to go into the material here, depending on his interest. It is enough to provide an account of how the matrix Λ appears in particle physics.
3. Generalize the aforementioned Mathematica program to an arbitrary subalgebra dimension $l < N^2 - 1$. How efficient is the program computationally?

Step 3 is here the most important for the task. For more info, see my webpage or contact me at marius.solberg@ntnu.no.

Contact: Marius Solberg marius.solberg@ntnu.no