Physics and mechanics of ice: international education in the University Centre in Svalbard and field works in the Arctic

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ABSTRACT

Local infrastructure in Longyearbyen, Svalbard, made it possible to establish the University Centre in Svalbard (UNIS) and provide regular semester-based education of Bachelor and Master students in the fields of Arctic Biology, Geology, Geophysics and Technology. The education process in Arctic conditions at 78°N includes lecturing, laboratory and fieldwork and brings an experience to live and work in the Arctic in an international community in addition to standard learning outcomes. The specifics of the research-based education and courses in ice physics and mechanics organized by Arctic Technology department at UNIS are described in the paper. Examples of field and laboratory work performed according to the course plans in the field of ice physics and mechanics are discussed.

KEY WORDS: research-based education, Arctic technology, sea ice, strength, scale effects

THE UNIVERSITY CENTRE IN SVALBARD

The University Centre in Svalbard (UNIS) was established in 1993 for teaching and research in the Arctic conditions. The UNIS campus is in Longyearbyen, the administrative center of Svalbard, Norway. The town is the seat of the Governor of Svalbard. It is the world's northernmost settlement of any kind with more than 2,000 permanent residents. UNIS is a state-owned limited corporation, owned and administered by the Norwegian Ministry of Education and Research.

The first 23 students arrived to UNIS to study Arctic Geology (AG) and Arctic Geophysics (AGF) in the autumn of 1993. In 1994 the department of Arctic Biology (AB) was established, and education in Arctic Technology (AT) started in 1996. This structure of scientific departments at UNIS has not changed since, but the number of students increased significantly. In 2019, 772 students from 43 nations spent shorter or longer periods at UNIS, including both course students and guest master's students. In addition, 12 PhD students were registered at the institution.

In education UNIS keeps a proportion of 50% international students and Norwegian students. The proportion of student nationalities in 2017-2019 were as follows: Norway (33%), Nordic Countries (9%), Germany (16%), Russia (3%), United Kingdom (6%), Netherlands (8%), Canada (1%), France (2%), USA (5%), other countries (17%). In 2019 50% of students came from programmes of study at Norwegian universities, while the proportion of Norwegian citizens was 32%. This discrepancy is attributed to the fact that foreign nationals are admitted to ordinary programmes of study at Norwegian universities. UiT – The Arctic University of

Norway (in Tromsø) is the Norwegian university that sends the most students to UNIS, closely followed by the Norwegian University of Science and Technology (NTNU).

Most of the course plans offered by UNIS includes fieldwork in the Svalbard region. Students must pass a one-week safety course before fieldwork organized by the Section of operations and field safety. The safety course includes lectures on natural hazards and methods to handle own safety, practical training on shooting and snow scooter driving, field exercises to survive in cold and icy environments. UNIS provides snow mobiles and clothes for the fieldwork The Section of operations and field safety offer support inorganizing and carrying out of fieldwork. Fieldwork organized by different scientific departments of UNIS assumes assigned technical personal qualified for each type of the fieldwork.

Laboratory facilities at UNIS are intended for the investigations in biology, chemistry, geology, space sciences, physics, and mechanics. There are three cold laboratories, and several freezers to store samples. The UNIS laboratories offer good support to work with samples collected during the fieldwork. The Kjell Henrikson Observatory (KHO) opened in 2008 and provides excellent conditions for the investigations in space physics. The UNIS Library provide books for the courses and for the research in the fields of Arctic science andhas subscriptions for main serial publications (journals and conference proceedings) according to the interests of the scientific departments at UNIS.

Research and educational activities at UNIS are realized in close cooperation with mainland universities and the research community in Svalbard, including the Russian Research Center in Barentsburg and Polish research station in Hornsund. UNIS students work in the laboratories, perform fieldwork, and stay overnight in Barentsburg. All lectures at UNIS are given in English, and all official information and documents are written in English, including exams. Students from different countries communicating in English with each other give them very good language experience and new contacts which are valuable for the future There is no tuition at UNIS, except a small semester fee. Main expenses of students coming to UNIS for the courses are related to the traveling, lodging and food.

ARCTIC TECHNOLOGY AT UNIS

Since 1996 Arctic Technology department (AT) has organized teaching and research in the fields of geotechnical engineering, environmental chemistry, hydrology and applied oceanography, coastal and offshore engineering, physics and mechanics of ice, and renewable energy. The number of courses organized by AT department each year are of about 15. AT runs BSc 2-4 courses while the other courses are for MSc and PhD students. MSc courses are usually combined with PhD courses. PhD students follow the same course with MSc students, but have different reports and exam questions. All courses include lectures, work in laboratory and fieldwork. The assessment is based on the results of reports prepared after the laboratory and fieldwork and exam in oral or written form.

In order to be admitted to AT courses, students need to have a background in chemistry or mechanical engineering. Selection of students for the courses is provided by the department of Academic Affairs in close contact with AT professors. Engineering background assumes good knowledge of basic mathematics and physics at BSc or MSc level. In some years AT run interdisciplinary courses in hydrology and environmental chemistry for BSc students. Students from different universities over the world can apply to study at UNIS by the web: www.unis.no. Students of 5-6 nationalities are usually presented in one student group.

BSc courses are extended over entire semester, while MSc/PhD courses are shorter, e.g., their duration varies from two weeks to one month. Courses for BSc students are run by professors having full time position at UNIS, while professors responsible for MSc/PhD courses can have adjunct position at UNIS. UNIS supports the invitation of guest lecturers and guest researchers. Guest lecturers usually teach specific topics 10-12 hours in one week. Guest researchers are involved in the field and laboratory work.

Time frames of the fieldworkare determined by environmental conditions and weather. It influences the course plans by specifying of the time assigned for lecturing, laboratory works, fieldwork, projects preparation, presentations, and exam preparation. The practice shows that BSc students may follow two courses at the same time, and MSc students may take a package of three courses following one by one with small overlapping. Such plan provides necessary amount of ETC points according to the educational program in Europe. UNIS offers course packages to help students to organize their education at UNIS. The course package in the AT department offered for students with chemical background includes courses in environmental chemistry, toxicology, and pollution. Package for students with engineering background includes courses in geotechnical engineering, offshore engineering, ice mechanics, and applied oceanography.

Exploration of Arctic environment is usually not the last goal for students since Spitsbergen is exotic place. Participation in fieldworkis a component of this exploration. Motivation of students to study theory is growing when they understand that it is necessary for the fieldwork. Another motivation to study at AT courses is related to the experience to be involved in industrial projects in the Arctic. Combination of student fieldworkwith the fieldworkfor research projects helps to reach it. Students become very interested if results of their laboratory and field works are useful for the practice.

Spring semester starts at UNIS in the middle of January by one-week safety course. Lecture materials are given in January and February in completely dark time. Fieldworkon land fast ice are possible in March – April when duration of light time of a day is long enough, snow cover allows to drive snowmobile, and sea ice thickness is greater 40 cm. One week of the fieldworkmeans that students go on the fieldworkon the Monday, return on the Thursday, and clean equipment after the fieldworkon the Friday. The actual time of the work is 2-3 days. Depending on the type of the fieldworkit may be needed to prepare the place for student works preliminary. It is done when the fieldworkfor a research project starts in the week before the student fieldwork, and students arrive to the place of running research fieldwork. They join the research group and learn from researchers how to organize tests and use scientific equipment. Another type of fieldworkis related to sampling for the laboratory investigations, or it can be just an excursion to observe Arctic environment or engineering structures. Such work can be organized by one day trip from Longyearbyen.

Table 1 shows student workload on the Spring BSc course AT-211 “Ice mechanics, loads on structures and instrumentation”. Students spend similar times for the lecture in auditoriums and for the field and laboratory work including preparation of the reports. Such distribution corresponds well to the natural conditions and local climate in Spitsbergen. Lecturing is organized in the dark time in January and February, the fieldworkperiod is in March and April. The written exam is in the beginning of June. Students can take written exam only if all reports are delivered before the exam. Total assessment consists of grades for the reports (60%) and grades for the exam (40%).

Local infrastructure is very important for the fieldworkin cold conditions. For example, organizing of mechanical tests on land fast ice is possible if warm lodging and food are available on relatively small distance (less then 5 km) from the place of the fieldwork. Warm room is needed for the maintenance of equipment during the fieldwork. Lodging should correspond to the number of students (~ 15), researchers and technical staff (~ 10). In Spitsbergen such facilities are available in Longyearbyen, Barentsburg, Pyramiden and Svea.

The sea is not frozen during last years near Longyearbyen and Barentsburg. Mining activity in Svea is stopped after 2019. The organizing of fieldworkon land fast ice in the Van Mijenfjorden is possible only if warm lodging will be provided in Svea. The other potential place of the fieldworkon land fast ice is near Pyramiden.

Table 1. Student workload on AT-211
"Ice mechanics, loads on structures and instrumentation"

<table>
<tr><th rowspan="2">Lecturing</th><th rowspan="2">Lab works</th><th colspan="2">Field works</th><th rowspan="2">Preparation of reports</th><th rowspan="2">Presentations</th><th rowspan="2">Exam</th></tr>
<tr><th>LFI</th><th>Cruise</th></tr>
<tr><td>40-50 h</td><td>1 week</td><td colspan="2">1 week (land fast ice)</td><td>3 weeks</td><td>6 h</td><td>3-4 h</td></tr>
</table>

Ship cruises make courses more popular for students. The duration of cruises varies from 5 to 10 days depending on the course budget and availability of ships for the rent. Passenger capacity of ships rented for the cruises influence the number of students on courses. If the number of students on courses is smaller 10, then two courses can go in the cruise by the same ship. Practice has shown that joining of two courses in one cruise can not be productive because of different tasks of the fieldwork. In my experience joint cruises with students from the course on environmental chemistry and students from the course in physics and mechanics of sea ice were successful because students performed different types of works (chemistry: pollution analysis of ice and snow, and ice mechanics: measuring of ice strength) at the same place with similar time frames. At the same time joint cruises with students from the course in oceanography were not successful because the tasks of oceanographic works assumed regular change of the workplace while tasks of ice mechanic course assume longer stay on the same floe.

MSc and PhD students may visit UNIS to perform project work at the UNIS campus. This student activity needs to be confirmed by a contract signed by the study administration and supervisors from both the home university and UNIS. Expenses of students coming to UNIS for project work are related to the travel, lodging, food, rent of snowmobiles, and buying of specific equipment. UNIS provides existing equipment and laboratories for free for MSc and PhD students registered at UNIS. Usually, their projects are planned and supported by research projects at UNIS, and in addition can be incorporated into the plans of the laboratory and fieldworkof UNIS courses.

TEACHING OF ICE PHYSICS AND MECHANICS

Physics and mechanics of ice can be considered as very specific science related to geophysics (polar oceanography, climatology, glaciology, space physics), hydrology (river ice jams, floods, hydro-energetic) and engineering (icing of plane and structures, ice actions on structures, performance of ice breakers). Ice based materials and composites are used in civil engineering and tunnel construction. Cryo-medicine and biology probably also should be mentioned as sciences where influence of ice on living matter is under the consideration. Properties of ice friction with different materials are important for sport (skating, bobsled, curling). From the other side ice in natural condition perform crystalline anisotropic material which temperature is closed to the freezing point. The investigation of ice properties is useful for deeper understanding of the material behavior in the range of high temperatures. Sea ice matrix includes liquid brine trapped from sea water and gases formed due to chemical reactions associated with precipitation of salts inside brine pockets and phase changes. Depending on the temperature and salinity sea ice becomes permeable by liquid brine. Dislocation dynamics is a physical mechanism explaining the evolution of ice properties by deformations. Thus, physics of ice and sea ice is complicated and confused.

Mechanical properties of fresh ice are very dependent from the temperature and granular structure of ice, and mechanical properties of sea ice depends also on the salinity. Ice is very brittle material by relatively high strain rates, but strain rate thresholds are very different for compressive and tensile deformations. Ice demonstrates viscous and creep properties at relatively low strain rates. Granular structure of ice changes by low strain rates and it is very stable at high strain rates and by relatively fast changes of the temperature. Sea ice permeability can influence mechanical processes, and ice deformations may change the permeability. Thermal expansion of sea ice can occur with negative coefficient in case of low permeability, while it is similar thermal expansion of fresh ice in case of high permeability. Mathematical models describing mechanical processes in ice depend on the process under the consideration. Standard documentation used by companies for the design and construction of structures on the Arctic shelf includes a set of rules used, for example, for the estimates of bearing capacity of floating ice, global ice loads on structures of different sizes and local ice loads on their structural elements, ice loads on ships etc. Future specialists willing to work in companies involved in the Arctic projects should be able to understand and select rules depending on actual situation. AT courses (BSc AT-211, MSc/PhD AT 332/338) in ice physics and mechanics are focused in this direction. Examples of calculation of ice characteristics and driving forces influencing drift ice are selected from ISO 19906 and discussed on the lectures. Then, laboratory and field experiments are used to confirm or criticize selected formulas and criterions.

Continuum mechanics gives solid background for the formulation of mathematical models based on the laws of mass, momentum and energy balance and physical assumptions on rheological properties of a material. Since continuum mechanics is studied at different levels in different universities the AT courses include several lectures on basic principles and conceptions of continuum mechanics in the beginning of the courses. It is important to explain students in the beginning of the course that they will need to use lecture materials for the data processing, and then it should be confirmed by real activities according to the course plan. The theoretical materials should be in a balance with experimental activities. Complicated theoretical lectures can be not received by students coming to explore Arctic.

In the Spring semester, students get their first ice-handling experience in the cold laboratory. They investigate processes of water freezing, ice formation, and thermal deformations of ice caused by changes of the room temperature. Students prepare thin sections to observe granular structure of ice and perform mechanical tests with beams and cores of fresh and sea ice harvested in previous seasons. In mechanical tests students measure elastic and viscous properties of ice, and different types of ice strength. Students should deliver reports after the laboratory work.

Field works of the Spring semester are organized on land fast ice in the Van Mijen Fjord of Spitsbergen and on drift ice in the Barents Sea. Special closes, driving of snowmobiles in Spitsbergen in Arctic environment, possibility to meet polar bear and other unusual events spread attention of students during the field works. Different and strong impressions make learning topics less visible. It is impossible to avoid it, but it is important to understand how to return students to the work plan and make them involved in the field activity in relatively short time. Teacher should be able to make group of about 15 students busy after they arrive on the ice during less than one hour. It is reached by splitting of students in several subgroups by 3-5 students and joining of each subgroup to the organizing of selected test. Each student subgroup changes activity after the test is finished. During the test each student subgroup works under super-vising of 2-3 experience researchers mounting test rig, installing sensors, and recording data. Students help to prepare ice for the test, take ice samples to measure salinity, and observe the test. Preparation of each test may take several hours. For 2-3 days students participate in 3-4 tests of different types and got the field data for the processing. They need to deliver reports after the field works.

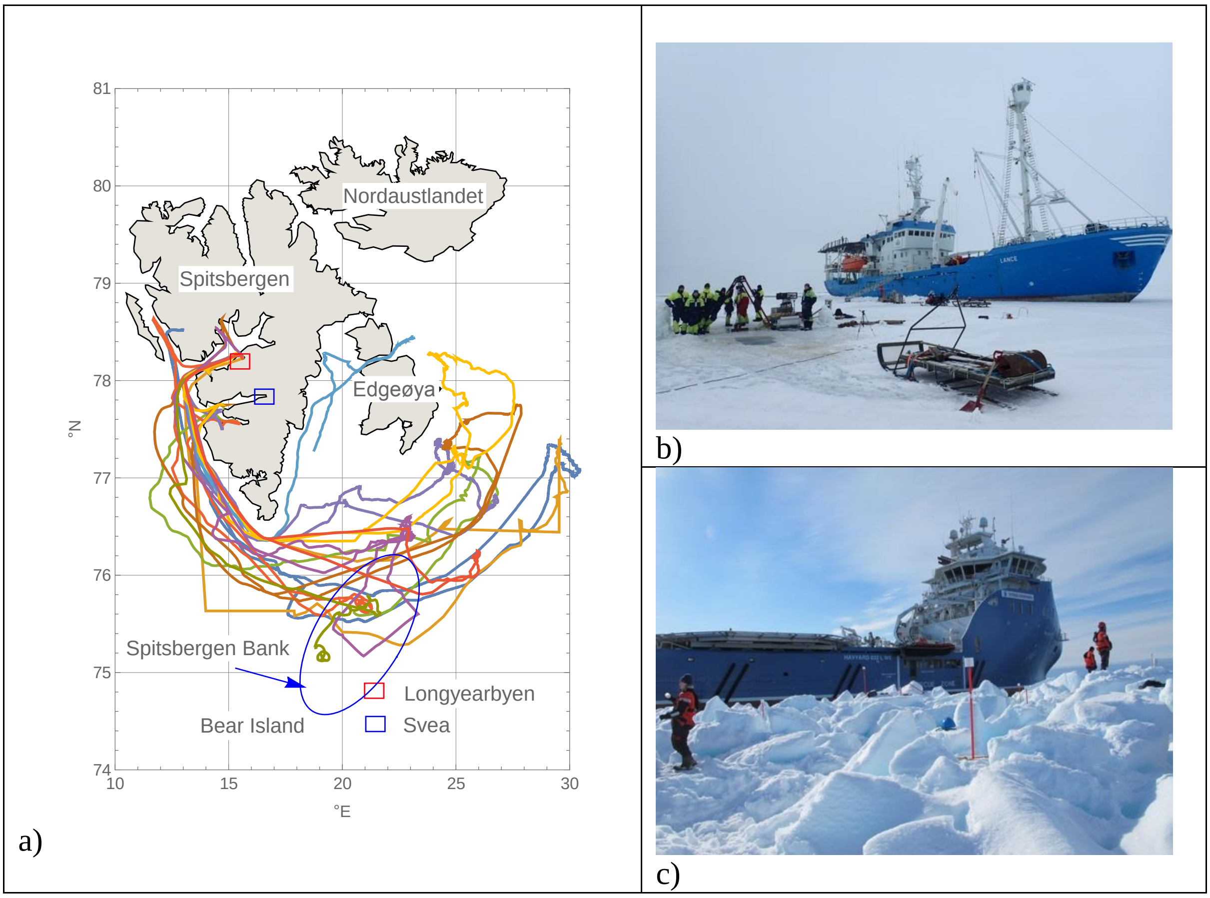


Figure 1. Trajectories of the cruises (a) of RV Lance (b) and Polarsyssel (c) organized for AT-211 course.

Similar system to work by subgroups is used in the field works on drift ice during the cruises. Specific of the cruises consists in the finding of place for the field works on drift ice in relatively short time. Ship tracks of the cruises organized for AT-211 course since 2007 are shown in Fig. 1a. Ice conditions were different in different years, and ice performance of ships rent for the cruises was also different. In 2007-2016 RV Lance of A-class (Fig. 1b) was rent for the cruises. Lance didn't have problems to penetrate in solid ice. Usually, we spent 3 days to find proper floe, then students worked on the floe for 2-3 days, and 2 days were spent to returned in Longyearbyen. Since 2017 supply vessel Polarsyssel of B-class (Fig. 1c) is rent for the cruises. Polarsyssel has higher speed on open water but doesn't want to go in solid ice and may only approach to a floe. Field works by Polarsyssel were organized on Spitsbergen Bank where sea ice consists of floes with diameters of 20-30 m. In two cruises Polarsyssel moored to selected floes, and in two cruises we used plastic boats Polarcirkel to go on the ice from the ship.
Field works in the cruises included ice strength tests, measurements of sea water characteristics in the boundary layer below ice, investigation of ice ridges morphology, and observation of ice drift. Usually, several lectures on oceanography and hydrodynamics are organized before the cruise. Ice strength tests were performed with the equipment used for the field works on land fast ice. CTD recorders and acoustic sensors ADCP and ADV were used to measure sea water

characteristics (temperature, salinity, velocity). Morphological investigations of the structure of ice ridges were performed by drilling and laser scanning. GPS antennas and buoys were used to monitor ice drift.

MSc/PhD course AT-332/832 "Physical environmental loads on Arctic coastal and offshore structures" is organized in October-November. The field works organized in the harbor area of Longyearbyen to measure wave action on floating piers, and on the ice of freshwater lake near Longyearbyen. Laboratory works included experiments in wave tank and tests in the cold laboratory. Course AT-332 was planned as an extension of AT-211 for the students decided to perform their MSc project at UNIS in the field of ice mechanics and offshore engineering. Lectures on Arctic offshore engineering are included in the program of two weeks course AT-327 "Arctic offshore engineering" in October.

EXAMPLES OF MEDIUM AND SMALL-SCALE TESTS ON ICE STRENGTH

Small-scale and medium-scale tests are performed to demonstrate rheological properties and to measure strength of sea ice and fresh ice. The sizes of ice samples in small-scale and medium-scale tests were respectively of about 10 cm and 1 m. The scale factor is estimated about 10. Medium-scale tests were performed in the field where the vertical size of samples made in floating ice was equal to the ice thickness. Small-scale tests were performed in the field and in the cold laboratory both. Comparison of small-scale and medium-scale tests performed with samples taken from the same ice helps to understand scale effects for different types of ice at different temperatures. Scale effects are very important for the estimates of ice loads on offshore structures (ISO 19906). Scale effects are related to increasing crack sizes in larger ice samples and dependence of ice failure types from the scale.

Students learned the influence of natural conditions on the ice characteristics by the comparison of the results of laboratory and field tests. In natural conditions sea ice has specific distribution of temperature and salinity over the ice thickness changing during the delivery of the ice samples to the laboratory and storage time before testing. Granular structure of ice in ice failure zones also may change with time. Ice samples taken from the failure zones can be damaged during transportation. Therefore, the analysis of thin sections of ice was also performed in the field.

Examples of small-scale and medium-scale tests performed with students during the works in the UNIS laboratory and in the field works on land fast ice and on drift ice are shown in Fig. 2-5. It includes strength tests on compression (Marchenko et al., 2918), tension (Chystiakov et al., 2016), indentation (Karulin et al., 2014), bending (Karulina et al., 2019) and torsion (Murdza et al, 2016). The beam length in medium-scale tests varied from 1 to 5 m. In each test measurements included records of forces and displacements/deformations. The ice structure was analyzed by photographs of thick sections and thin sections of ice, and by laser scanning of ice samples after tests. The equipment used in the medium-scale tests was designed and constructed under the support of the SFI project Sustainable Arctic Marine and Coastal Technology (SAMCoT, 2012-2019).

Comparison of compression strengths obtained in the compression tests shown in the left panels of Fig. 2,3 showed that scale effect is stronger when the ice temperature is lower. The mean temperature of floating ice in medium-scale compression tests was higher than -6^{o}C. The compressive strength varied around 1 MPa without visible dependence from the liquid brine content. Small-scale compressive strength was measured in three surveys (Moslet, 2007). The mean values of the strength in the surveys were 0.8 MPa, 2.3 MPa and 4.6 MPa. The mean temperatures of ice cores were respectively -1^{o}C, -6^{o}C, and -10.4^{o}C. Therefore, the scale factor between small-scale and medium-scale strengths is estimated of around 2 for the temperature of around -6°C, and around 1 when the temperature is above -2°C.

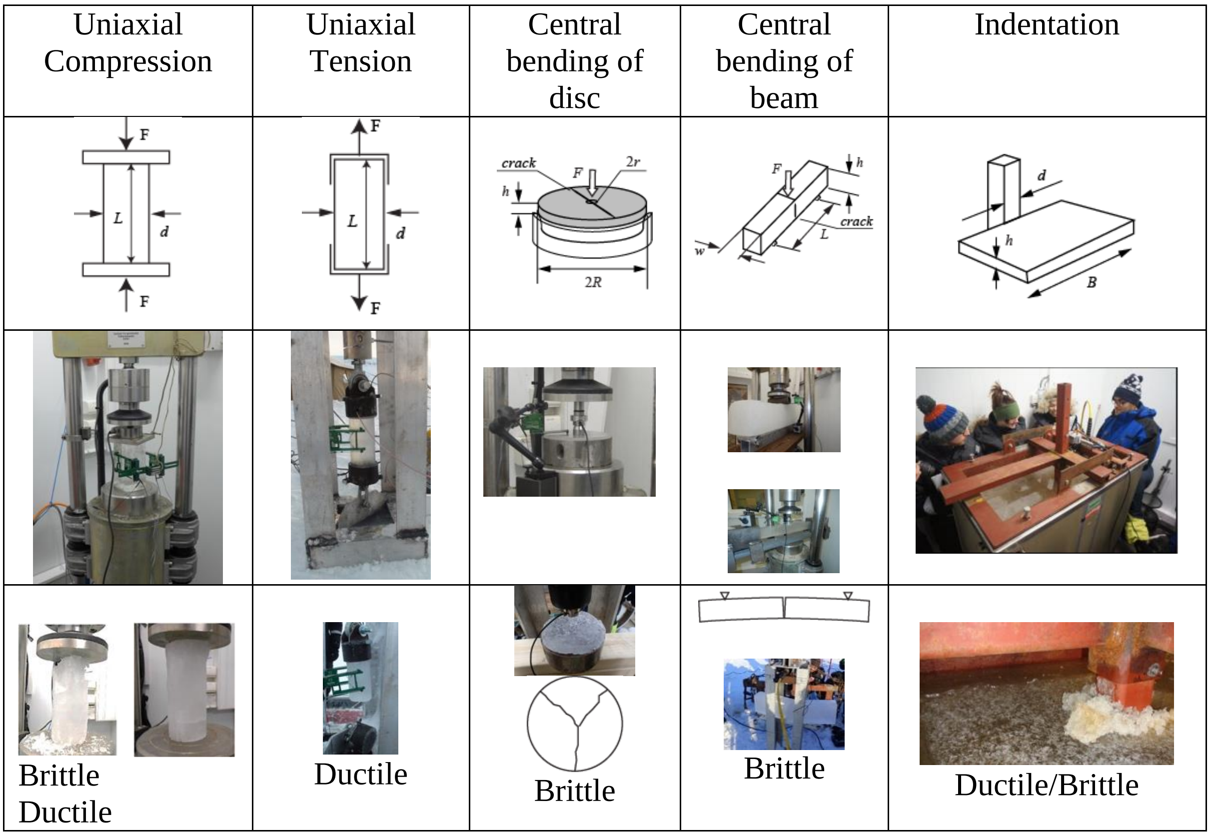


Figure 2. Small-scale tests performed in laboratory and field conditions.

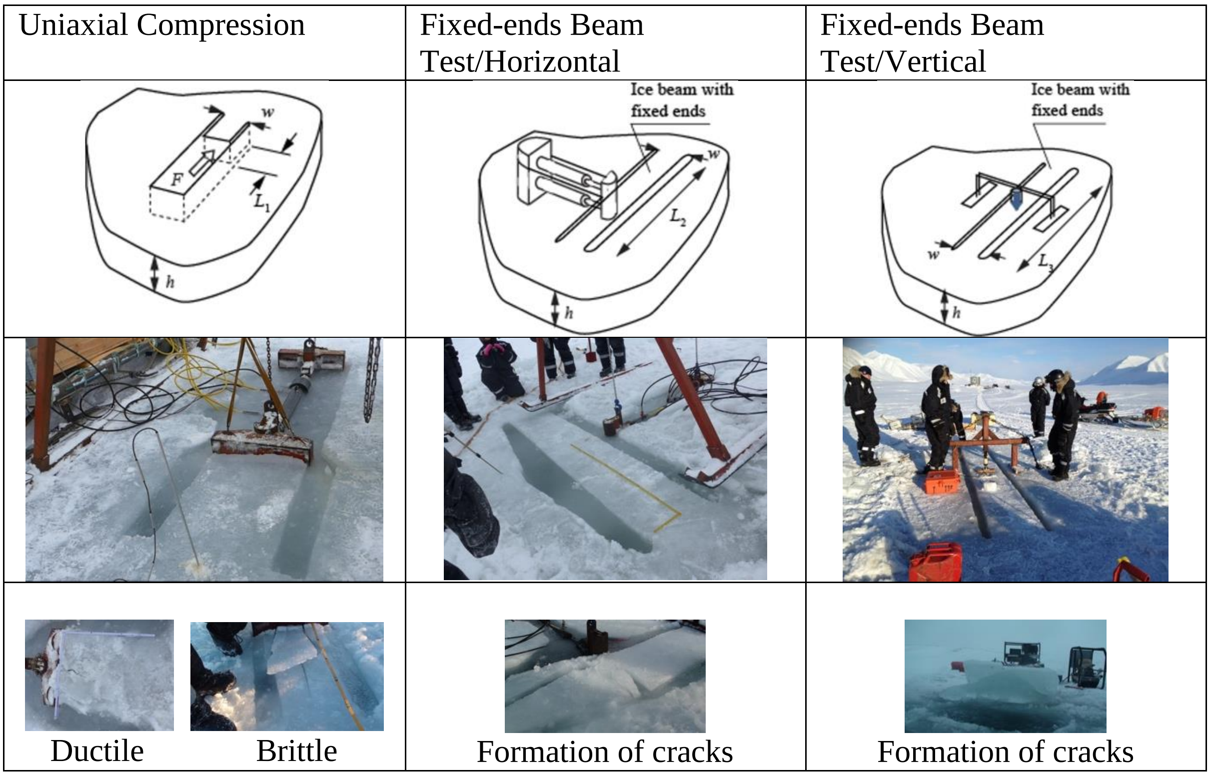
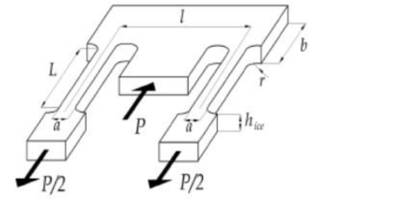
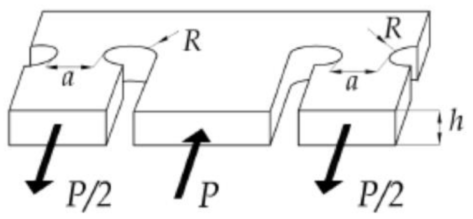
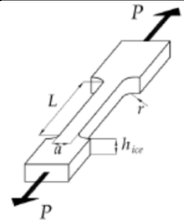


Figure 3. Medium-scale compression tests performed in field conditions

<table>
<tr><td>Uniaxial Tension with Two Long Necks</td><td>Uniaxial Tension with Two Short Necks</td><td>Uniaxial Tension with One Neck</td></tr>
<tr><td>
</td><td>
</td><td>
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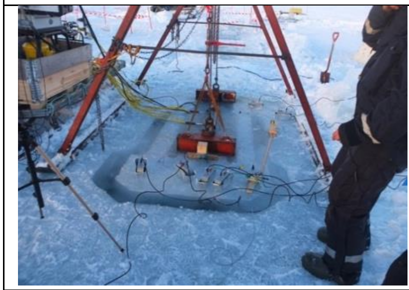
<tr><td></td><td></td><td></td></tr>
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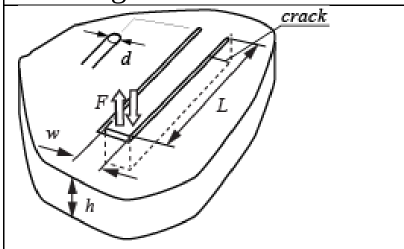
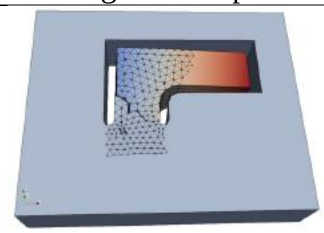
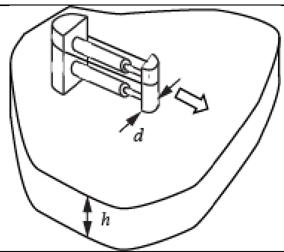
Figure 4. Medium-scale tests on tensile strength performed in field conditions

<table>
<tr><td>Bending of Cantilever Beam</td><td>Bending of L-shape Beam</td><td>Indentation</td></tr>
<tr><td>
</td><td></td><td>
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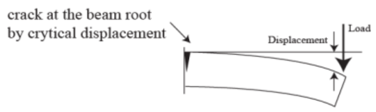
<tr><td>
</td><td>

Crack</td><td>
Crashing</td></tr>
</table>

Figure 5. Medium-scale tests on ice bending, torsion and indentation

The diameter of cylindrical indenter was 15 cm, and typical thickness of ice in the tests was 50-70 cm. It determines representative nominal contact area of about 0.1 m^2. The strain rates varied within 0.001-0.005 s^{-1} in the tests. Top layer of ice crushed when indenter penetrated in the ice. Bottom part of ice had ductile failure. We observed horizontal cracks splitting bottom and top layers of ice in the front of the indenter. Nominal ice pressure in the tests varied within 3–6 MPa. It corresponds to the level of ice pressure measured in the medium-scale tests performed on Canada shelf despite higher strain rates of about 0.1 s^{-1} in the tests (Frederking, 2020).

Figures 6 and 7 illustrate medium-scale and small-scale changes of ice structure in medium-scale indentation tests shown in the right panel of Fig. 5. Figure 6a shows the ice block was cut from sea ice after the test. The horizontal crack formed in the front of cylindrical indenter in the bottom part of the ice is visible in Fig. 6a. Figure 6b shows the image of the ice block made by the laser scanning after the test. Similar horizontal crack is visible on the sides of the block. Figure 6c shows the photograph of thick horizontal section of ice taken in the front of the indenter. It is possible to distinguish zones where the ice structure changes from natural ice to compressed ice (zone 1), and from compressed ice to highly deformed ice near the indenter surface (zone 2). Thin sections in Fig. 7 show changes of the ice structure with approaching to the indenter. The diameters of grains become very small near the indentation surface. There is a layer of about 1 cm thickness near the indentation surface with very fine grains separated by a crack from surrounding ice (Fig. 7c). The crack shape repeats the shape of the indenter. Similar structures were observed in the tests with borehole jack (Sinha et al., 2012).

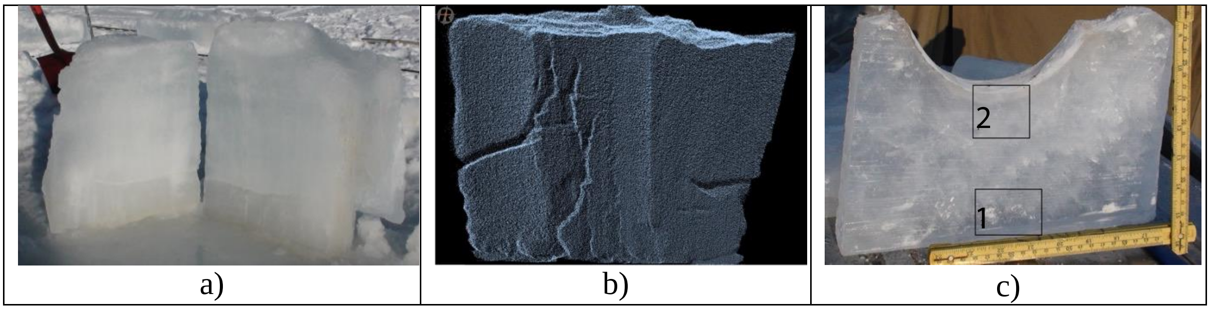


Figure 6. Vertical sections of ice after indentation test (a), laser scan of ice blocks after taken from the ice after indentation test (b), section of ice taken from the ice in front of cylindrical indenter (c).

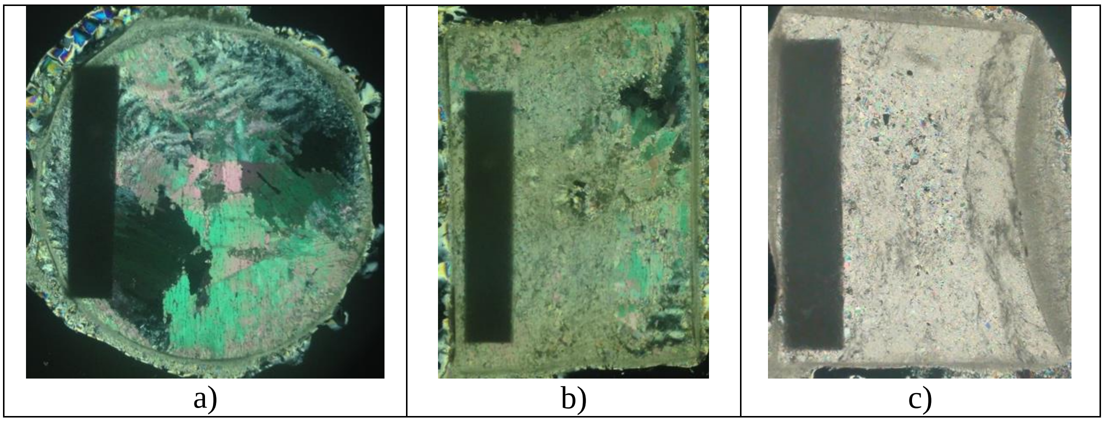


Figure 7. Thin section of natural sea ice (a), thin sections made from the ice in zone 1 (b) and 2 (c). The length of black strip is 5 cm.

Figure 3a shows compressive strengths versus the liquid brine content obtained in the tests on uniaxial compression, tests with fixed-ends beams, and indentation tests (Marchenko et al., 2018). Black line shows the envelope of uniaxial compression strength measured in small-scale tests with horizontals cores of sea ice (Moslet, 2007). In the tests with fixed-ends beams (Table 3, middle column) the beams are broken in the middle because of the compression (Sodhi, 1998). Blue and yellow points in Fig. 3a show that compressive strength of ice obtained in these medium-scale tests was higher than in the medium-scale tests on uniaxial compression of short cantilever beams (Table 3, left column). Green point in Fig. 3a show that compressive strength obtained in medium-scale indentation tests (Table 5, right column) was the highest. Difference of compressive strengths measured in these medium-scale tests is explained by lateral confinement of ice. Compression strength growths with increasing confinement. The confinement was maximal in the indentation tests.

The diameter of cylindrical indenter was 15 cm, and typical thickness of ice in the tests was 50-70 cm. It determines representative nominal contact area of about 0.1 m^2. The strain rates varied within 0.001-0.005 s^{-1} in the tests. Top layer of ice crushed when indenter penetrated in the ice. Bottom part of ice had ductile failure. We observed horizontal cracks splitting bottom and top layers of ice in the front of the indenter. Nominal ice pressure in the tests varied within 3–6 MPa (Fig. 3a). It corresponds to the level of ice pressure measured in the medium-scale

tests performed on Canada shelf despite higher strain rates of about 0.1 s^{-1} in the tests (Frederking, 2020).
The mean value of tensile strength 0.12 MPa obtained in medium-scale tests shown in Fig. 4 is equal to 12 % of the mean value of medium-scale compressive strength. Comparison with the results of small-scale tensile strength tests shown in Fig. 2 and with the results published by Timco and Weeks (2010) supports the scale factor 2. The value of flexural strength obtained in medium-scale tests shown in the left panel of Fig. 5 depends on the liquid brine content of the ice (Karulina et al., 2019). Medium-scale flexural strength is lower the values of flexural strength obtained in small-scale experiments (Timco and Burden, 1997; Krupina and Kubishkin, 2007). The difference depends on the type of small-scale test (Marchenko et al., 2017).

CONCLUSIONS

A combination of research and student activities planned for AT courses was very effective for the research and education in the field of ice mechanics. Students performed many small-scale tests. The results were used analyzed and compared with the results of medium-scale tests. Participation in the research field works made students more motivated and interested. The research-educational cooperation allowed to optimize budgets of research and educational activities both. Support of research and educational projects such as SFI SAMCoT (RCN, 2012-2019), SMIDA (SIU, 2012-2015), SITRA (SIU,2015-2019), and AOCEC (IntPart RCN, 2018-2020) was crucial for the organizing of the research and field works. Research projects gave possibility to design, construct and buy modern equipment, organize international research group focusing on the project topics. Educational projects allowed invite students and guest lecturers from relevant universities and provided the possibility for student to work with modern equipment under supervising of experience researchers. Collaboration of research groups working in the universities specialized in fundamental and engineering sciences supported by the projects SITRA and AOCEC was very effective. The scientific cooperation extended the study of pure mechanical properties of ice to deep investigations of physical processes accompanying ice deformation and failure, ice motion in water environment, and ice-structure interaction. New lecture topics and experimental activities were included in the study program of AT courses at UNIS. It helps to attract more students to UNIS, to understand physical processes in Svalbard region, and to develop fruitful cooperation with companies interested in Arctic based projects and local industry in Svalbard.

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