CONCRETE ICE ABRASION RIG AND WEAR MEASUREMENTS

Guzel Shamsutdinova[1], Paal B. Rike[1], Max A.N. Hendriks[1, 2] and Stefan Jacobsen[1]
[1]Norwegian University of Science and Technology, Trondheim, Norway
[2] Delft University of Technology, Delft, Netherlands

ABSTRACT
The wear of concrete material due to ice movement is a challenge for offshore and coastal structures. Concrete surfaces exposed to moving ice are subjected to wear at various rates depending on concrete and ice properties.
At NTNU, Department of Structural Engineering, concrete ice abrasion phenomena are studied both theoretically and experimentally. This paper describes the accelerated concrete ice abrasion rig which was comprehensively improved recently. Together with surface measurement equipment, it is believed that the new experimental facility will give new input for understanding of the underlying mechanisms of ice abrasion.

INTRODUCTION
Industrial exploration of the Arctic demands new materials to be utilized in severe conditions. Nowadays the behavior of a variety of materials is studied under ice sliding. There are such materials as polyethylene (Ducret, et al., 2005), metal coating (Abdelnour, et al., 2006), stainless steel (Abdelnour, et al., 2006), smooth painted steel (Frederking & Barker, 2002), heavily corroded steel (Frederking & Barker, 2002) and concrete (Jacobsen, et al., 2014; Bekker, et al., 2011; Fiorio, 2005). In the last decades concrete has been proven as a suitable material for offshore development. And in this paper we describe our concrete-ice abrasion test equipment.
Concrete-ice abrasion mechanisms are reviewed in Jacobsen et al. (2015). Although surface degradation can be consequence of simultaneous mechanical action, freeze-thaw cycles, chemical attack etc. the ice friction on concrete surface itself is presumably the severest attack. We continue to study this phenomenon by improved test methodologies and approaches. In this paper the accelerated concrete ice abrasion rig is presented.

CONCRETE -ICE ABRASION LABORATORY AT NTNU
The lab includes a rig for acceleration wear of a concrete surface under ice sliding and facilities for measuring wear and roughness. Although the concrete wear depends on many factors we have to decrease the amount of parameters and simplify test procedures. One choice is the use of fresh water ice instead of sea ice, to avoid particularly chlorides and the associated severe corrosion on rig details. The concrete-ice abrasion rig is located in a room with ability to keep negative temperature down to -20 degree of Celsius.

Concrete-ice abrasion rig
The heart of the concrete-ice abrasion lab at NTNU is the concrete-ice abrasion rig. It performs sliding interaction of a concrete sample and ice, Figure 1. This rig is based on a shaping machine that was modified by the mechanical and electronics workshops at Department of Structural Engineering. The assembled rig for concrete-ice abrasion test has

been used since 2008. Since that time it was partly improved (repaired) several times. Recently the rig was equipped with:

1. a new sliding bearing system, Figure 1(a);
2. a new vertical load cells, Figure 1(c);
3. engine for automatic movement of table with concrete sample, that simplifies changing of ice specimen significantly;
4. a new program with a more accurate feedback system for ice load control and high-frequency logging of friction.

The last item is the most important. This system enables to control vertical and horizontal load with response logging up to 500 Hz, i.e 50 times faster than before (10Hz). Previous test results (Greaker, 2014) did not indicate the peaks in friction coefficient plots, due to insufficient amount of data. So the new system is believed to solve this problem. The feedback - and logging system is programmed with National Instruments LabView and the hardware interface is a compact RIO chassis.

The purpose of the rig improvements is to perform tests more accurately including studies of roughness and friction. A new sliding bearing system, Figure 1(a), performs sensitive sliding, thereby improving the accuracy of the friction measurements during ice abrasion exposure. Two new vertical load cells under the concrete specimen, Figure 1(c), detect the load more sensitively. The maximum capacity for each of them is 10 kN (total capacity 20 kN).

The original shaping machine creates repeated, sinusoidal, sliding movements of the ice sample holder in horizontal direction. The sliding distance is constant and equals 200 mm. The sliding speed can be varied in the "Is-abrasiv 2014" software up to 0.6 m/s.

The ice sample, within the sample holder, (Figure 1) is under constant vertical load that is also controlled by the software. The motor in Figure 1 drives the vertical piston pushing the ice sample while it is worn down, and stops automatically when desired consumption level of ice is reached.

The horizontal screw fixes the concrete specimen towards a horizontal load cell, Figure 1(b). The maximum value of pretention is 7500 N to keep sample stable during the test. The software indicates vertical load as the sum of two load cells.

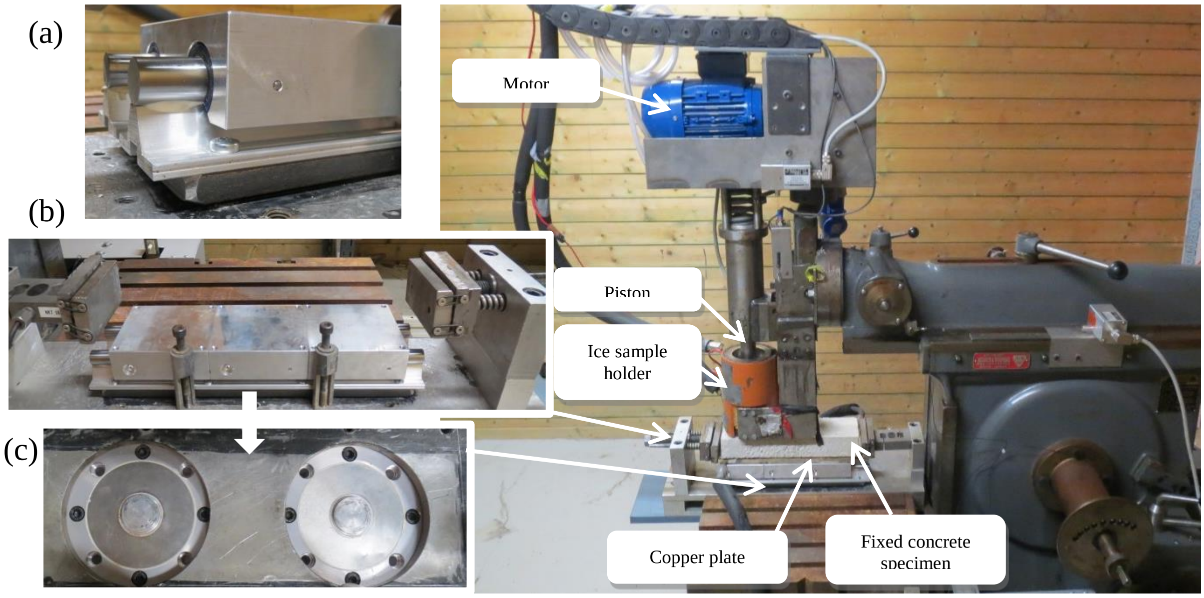
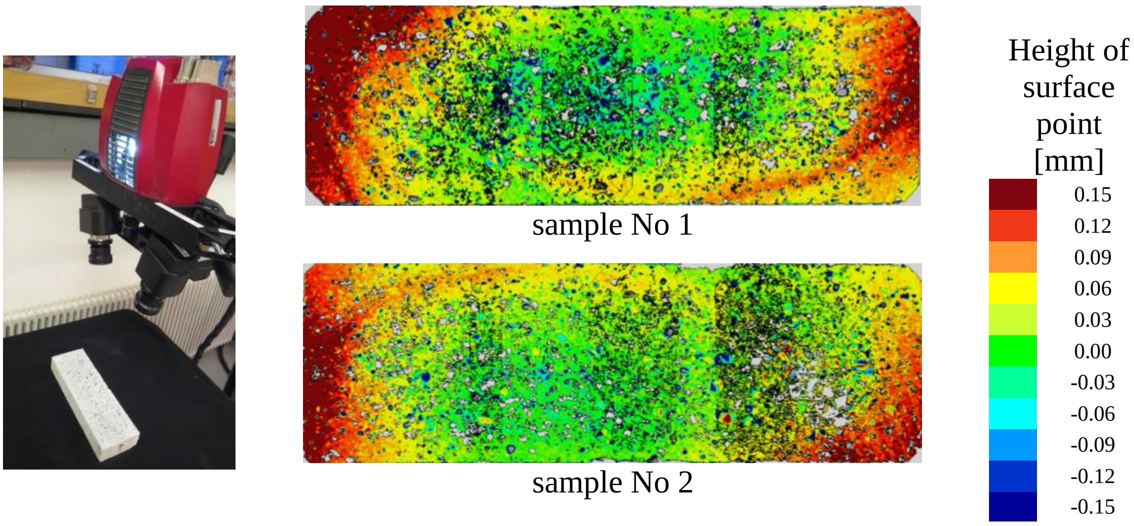


Figure 1. Concrete-ice abrasion rig: (a) - sliding bearing system;
(b) - horizontal load cells; (c) - vertical load cells – top view.

Both concrete and ice sample are under temperature control during the test. The concrete specimen temperature control goes through a steel-epoxy-copper coil-copper sandwich plate (Figure 1). The copper-coil in this sandwich plate is connected with a cooling liquid (alcohol) circulator. The temperature control of the ice sample goes through a separate circuit around the ice sample holder (Figure 1).
The Is-abrasive 2014 software displays the number of cycles, total sliding distance, sliding speed and loads feedback. The output includes two files, one of them with the friction parameters (time, position, horizontal and vertical loads) and another with all parameters (temperature, total distance, number of cycles).

Structured light 3D scanner
To increase the amount of information about abraded concrete surfaces compared to mechanical measurements, work on the 3D optical light scanner ATOS III SO (small object configuration) was made to develop it for concrete abrasion measurement (Shamsutdinova, et al., 2015). Figure 2 (b) shows surface 3D scans of concrete samples, which were tested before in Greaker (2014). Both concrete, samples with w/c = 0.60 with 40% volume of paste and granitic aggregate with 8 mm maximum particle size, were tested at ice pressure 1 MPa and sliding distance 500 m. Mechanically measured mean wear depth is 0.049 and 0.052 mm respectively for samples No.1 and No.2 (Greaker, 2014).
The scanner software creates a mesh based on the surface scan. The measuring point distance is 0.05 mm. There is a main disadvantage of working with a structural light scanner: dark zones on the concrete surface are not detected. As a result there are large and substantial number of holes of varying size in the mesh. But the ATOS software, with its post processing software GOM Inspect, has “closed the holes” based on the meshing interpolation procedure.
A preliminary comparison between mechanical and ATOS measurements on samples No.1 and No.2 shows 0.039 mm for both. Hence ATOS can be used to measure concrete-ice abrasion, with appropriate use of the GOM inspect software procedures including the closing of holes and numerical procedures for creating reference planes in the unabraded and abraded zones (Shamsutdinova, et al., 2015).



(a) (b)

Figure 2. (a) 3D optical scanner ATOS III SO;
(b) surface 3D scans of tested concrete samples.

The numerical hole filling procedure, however, modifies the surface topography so that roughness measurements become dubious from the data. Moreover, the procedure is time consuming with coupling of repeated scans to cover the whole surface. Together with the numerical hole filling- and the reference plane selection procedures this presumably also introduces the kind of vertical artefacts seen several places in the surface scans in Figure 2. In addition to the above mentioned work with the concrete ice abrasion machine we are therefore at present also developing a new abrasion measurement system based on laser.

FURTHER WORK

Before further studies of roughness and its effect on concrete ice abrasion we will implement the new abrasion measurement system. At first a full comparison between mechanical, ATOS and laser measurements will be performed on a series of 15 specimens that No.1 and No2 were a part of. Also some initial tests of friction will be made with the new sensitive concrete ice abrasion machine. Then ATOS and laser measurements will be used to study the effect on concrete-ice abrasion of concrete and ice surface roughness created in different ways in different types of concrete and ice. The results will be compared to numerical simulations of crack initiation during ice sliding on a concrete surface asperity. The objective is to get fundamental information on the mechanics of concrete-ice abrasion to better understand how to create concrete-ice abrasion resistant structures.

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