Concrete-Ice Abrasion: Laboratory Studies using a Sawn Concrete Surface

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ABSTRACT

Concrete-ice abrasion is a surface degradation mechanism due to ice-structure interaction especially relevant for concrete gravity-based structures in the Arctic offshore.

Experiment is the main evaluation method for concrete durability against ice abrasion. The paper presents NTNUs lab facilities and a 4 km concrete-ice abrasion test between a sawn concrete surface with $f_{c\ cube}$ = 110 MPa and unidirectionally grown fresh water ice. Results demonstrate the load cells response, coefficient of friction and a 0.03 mm/km abrasion rate measured with laser scanner. Further research is discussed.

Key words: Surfaces; Concrete; Ice; Abrasion; Experiment; Testing.

1. INTRODUCTION

The concrete-ice abrasion process has been defined as the surface degradation of concrete structures due to interaction with drifting ice floes. Several research groups have studied this topic through laboratory experiments [1,2,3,4,5,6] and field observations [1,7]. Hara et al. [8] recommended the concrete-ice sliding abrasion test, during evaluation of various test methods of concrete-ice abrasion resistance. Most experimental work the last 30 years has been based on the sliding interaction between ice and concrete, whether ice on concrete [4,5,9,10] or concrete on ice [2,5,11,12].

Our experimental method is based on the sliding of an ice sample along a fixed concrete sample. It controls exposure and measures relevant response parameters during concrete-ice interaction, including concrete-ice abrasion with a laser scanner. We used a concrete sample with a sawn surface, same as [5]. The wear rate of a surface with exposed aggregates is of great importance for the durability against concrete ice abrasion [12] and sawing also ensures a standard type of test surface.

2. EXPERIMENT

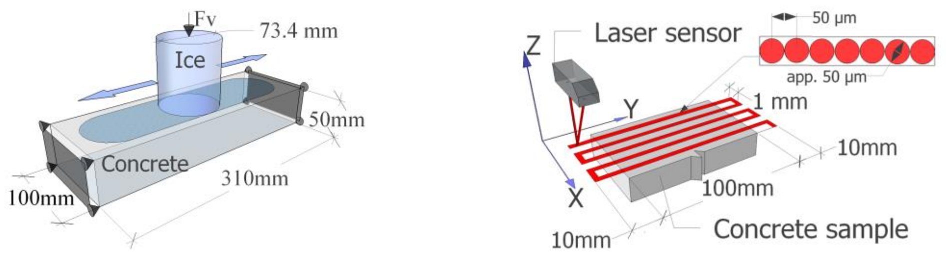
The experiments presented here include the simulation of concrete-ice abrasion with an abrasion rig, and laser scanner measurements of abrasion. The tests were performed in the abrasion laboratory at air temperature -10°C. The ice pressure was 1 MPa. The average sliding velocity was 0.16 m/s.

2.1. Abrasion machine

The abrasion machine simulated concrete-ice abrasion according to the principle in Fig. 1(a), with a sliding ice specimen along a fixed concrete sample. The machine makes the ice sample holder move in repeated sliding movements in a horizontal direction, with the average velocity 0.16 m/s. The piston continuously pushes the ice sample against the concrete surface with a 1 MPa load. A feedback system keeps the loading as constant as possible during the test while moving back and forth. The temperature in the concrete-ice abrasion lab is kept at −10 °C. The concrete sample temperature control goes through an aluminium heating plate below the concrete sample. The plate is connected to a controlled temperature liquid (alcohol) circulator. This means that the temperature of the concrete surface in the concrete-ice abrasion zone can be adjusted. The temperature of the concrete surface in the contact zone was measured with an infrared scanner.

2.2. Laser scanner

Recently, we developed a non-contact Laser Scanning measuring method (Fig. 1(b)) to measure concrete-ice abrasion. It allows scanning of the concrete surface with accuracy 10 µm in reasonable time. The laser moves continuously along the sample according to a predefined “snaking” path. The measuring point distance is approximately 50 µm in the Y direction, and the step size in the X direction, the sliding direction, is 1 mm (Fig. 1(b)). The measured data is transformed to a matrix of surface heights, with 1900x300 points.



(a) *(b)*

Figure 1 – (a) The principal scheme of an abrasion test, (b) simplified schematic of measurement process (not to scale)

2.3. Ice

Our abrasion machine is designed for fresh-water cylindrical ice samples. We used unidirectionally grown ice made from tap water. An ice mould made of Polyoxymethylene (POM) 13.3 mm thick and 370 mm high and covered with thermal insulation on the sides and the bottom is filled with tap water and put in a freezer at −20 °C for 48-72 hours. The freezing of the water starts at the top of the mould, but later it also takes place from the bottom. The upper part of the ice sample is transparent (unidirectionally grown ice) with very few air voids. The lower part of the ice sample contains a lot of air voids and unfrozen water. The ice sample is cut in two, and only the upper part is used for the test.

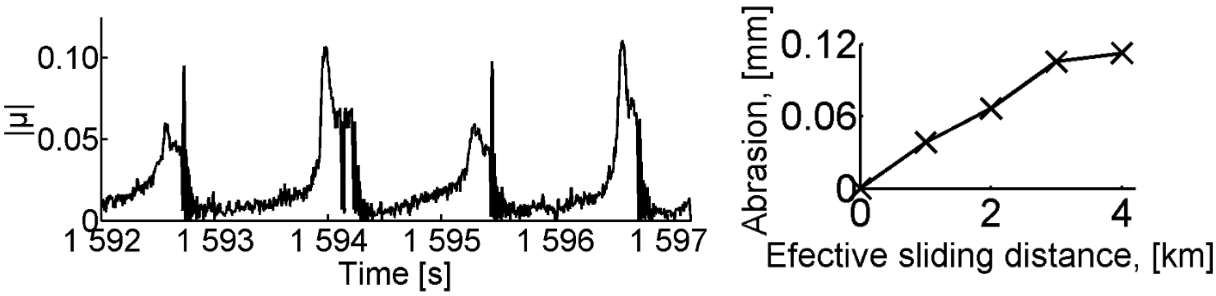
2.4. Concrete

The tested concrete sample was made of Norcem Anlegg (CEM I) cement and 2% Elkem silica fume substitution, fine aggregate (Årdal sand, 0-8 mm grain size) and coarse aggregate (Årdal, 8-16 mm grain size). The mix was made with the following proportions: W/(C+2S)=0.42, where W, C and S are the weight of water, cement and silica fume powder, respectively. The cement paste volume was 29.5%. Superplasticizing additive Dynamon SX-23 from Mapei was used to achieve flowing workability. The 28-day cube compressive strength of the concrete was 90 MPa, increasing to 110 MPa after curing in water at +20°C for 11 months, as the test started.

3. RESULTS

The data acquisition system logged horizontal and vertical load cells responses during the test at 500 Hz frequency. The coefficient of friction (COF) is plotted in Fig. 2(a). The highest COF corresponds to the turning points of the ice specimen where the ice sample makes a full stop. We distinguished the coefficient of kinetic friction (0-0.2) during sliding interaction, and the coefficient of static friction (0.05 – 0.10) at the turning points.

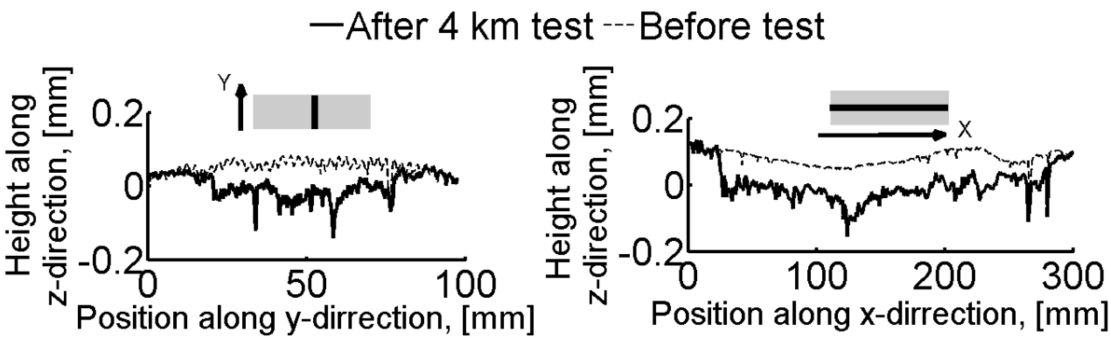
Laser scanning gave abrasion as the difference between the unabraded rim of the concrete sample and an abraded central band of 10 mm width as done with mechanical measurements in [5]. However, a much higher number of data points was collected with the laser scanner, so the calculation here was done for each millimeter of concrete sample length and each 50 microns across the 10 mm wide central band. Figure 2(b) shows the abrasion of sawn concrete sample.



(a) *(b)*

Figure 2 – (a) Coefficient of friction, (b) abrasion of sawn concrete surface.

Figure 3 shows the average profiles of the abraded central band (10 mm wide) along the sample width (Fig. 3(a)) and length (Fig. 3(b)), before and after 4 km abrasion test. The difference between two lines shows the abrasion.



(a) *(b)*

Figure 3 – Average profiles, of the central band (10 mm wide), of the sawn concrete surface before and after 4 km abrasion test: (a) along y-direction, (b) along x-direction (see inserts).

4. DISCUSSION AND CONCLUSION

The measured coefficient of kinetic friction is of the same magnitude as test results of other concrete-ice abrasion tests with the same sliding speed (0.16 m/s): 0.00 – 0.01 and 0.06 respectively [5,12]. The results of the abrasion depth were found similar to the previous study by

Møen et al., where concrete samples with cylindrical compressive strength from 72.8 to 147.8 MPa under similar experimental conditions had a maximum abrasion rate 0.025 mm/km of effective sliding distance. Beside coefficient of friction and wear rate, the ice failure mode, concrete surface roughness and wear particle characteristics are in the focus of our interest and being investigated in further works.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] Huovinen, S.: “Abrasion of concrete structures by ice” Cement and Concrete Research 23(1): p. 69-82 (1993)

[2] Bekker, A.T., Uvarova, T.E., Pomnikov, E.E., Farafonov, A.E., Prytkov, I.G., Tyutrin, R.S.: “Experimental study of concrete resistance to ice abrasion” Proceedings of the International Offshore and Polar Engineering Conference (2011)

[3] Hanada, M., Ujihira, M., Hara, F., Saeki, H.: “Abrasion rate of various materials due to the movement of ice sheets” Proceedings of the International Offshore and Polar Engineering Conference (1996)

[4] Fiorio, B.: “Wear characterisation and degradation mechanisms of a concrete surface under ice friction” Construction and Building Materials 19(5): p. 366-375 (2005)

[5] Møen, E., Høiseth, K.V., Leira, B., Høyland, K.V.: “Experimental study of concrete abrasion due to ice friction - Part I: Set-up, ice abrasion vs. material properties and exposure conditions” Cold Regions Science and Technology 110: p. 183-201 (2015)

[6] Tijsen, J., S. Bruneau, and B. Colbourne: “Laboratory examination of ice loads and effects on concrete surfaces from bi-axial collision and adhesion events” Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions, POAC (2015)

[7] Itoh, Y., Tanaka, Y., Delgado, A., Saeki, H.: “Abrasion depth distribution of a cylindrical concrete structure due to sea ice movement”. International Journal of Offshore and Polar Engineering, 6(2): p. 144-151 (1996)

[8] Hara, F., Y. Takahashi, and H. Saeki: “Evaluation of test methods of abrasion by ice movements on the surface of reinforced concrete structures” Concrete Under Severe Conditions Environment and Loading p. 475-484 (1995)

[9] Saeki, H., Ono, T., Nakazawa, N., Sakai, M., Tanaka, S.: “Coefficient of friction between sea ice and various materials used in offshore structures” Journal of Energy Resources Technology, Transactions of the ASME 108(1): p. 65-71 (1986)

[10] Jacobsen, S.: “A Norwegian concrete-ice abrasion laboratory” Nordic Concrete Research Publ.No.50 ISSN 0800-6377, pp. 119-122 (2014)

[11] Hoff, G.C.: “Evaluation of ice abrasion of high-strength lightweight concretes for arctic applications” Proceedings of the International Offshore Mechanics and Arctic Engineering Symposium (1989)

[12] Itoh, Y., Yoshida, A., Tsuchiya, M., Katoh, K., Sasaki, K., Saeki, H.: “An experimental study on abrasion of concrete due to sea ice” Twentieth Annual Offshore Technol. Conf. pp. 61-68 (1988)