Ice abrasion testing of high performance concrete for offshore structures

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ABSTRACT

Offshore concrete structures exposed to drifting sea ice have abrasion of the concrete surface caused by the mechanical contact between ice and concrete in the order of 0.1 to 1 mm per year. The concrete-ice abrasion laboratory at NTNU, and results of our recent research of the laboratory simulation of concrete-ice abrasion, showed average abrasion depths of 0.01–0.35 mm for high-performance concrete after 3 kilometres of sliding ice, a severe-mild wear-transition, that abrasion is related to cutting of peaks, formation of valleys, aggregate protrusion by wear of ITZ. The strength – abrasion relation proposed by Huovinen was less clear due to the severe-mild transition.

Key words: Concrete, ice, abrasion, ITZ, surface topography.

1. INTRODUCTION

Research on the concrete-ice abrasion problem has to a large extent been done experimentally in various laboratories in North-America, Europe, Russia and Japan. The experimental methods have varied for different laboratories, but so far most work has been based on the sliding interaction between ice and concrete.

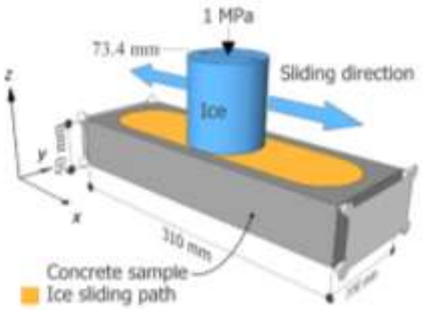
The scope of this research has been to investigate how the tribology parameters friction, surface roughness, topography and wear particle characteristics are affected by ice sliding on various types of concrete and surfaces. The laboratory and test procedures (low-temperature wear machine, ice making, laser scanning of wear) were further developed and a series of high performance off-shore type concretes with different surfaces were made and studied. This paper presents a few excerpts of a PhD project. The entire work is reported in the thesis [1].

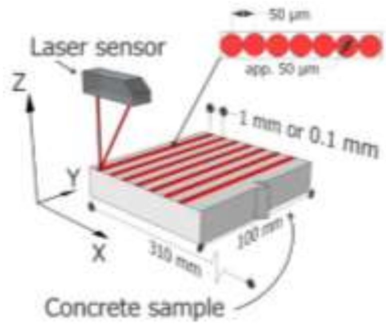
2. EXPERIMENTAL SET-UP AND MATERIALS

2.1 Concrete-ice abrasion lab: abrasion rig and laser scanner

The experiments took place in a cold room −10 °C. The lab performs sliding of fresh-water ice samples on concrete surfaces with average pressure of 1 MPa and average sliding velocity of 0.16 m/s, the scheme of the concrete-ice abrasion test is in Figure 1 (a). The effective sliding distance for each concrete sample was 3 km. The temperature of the concrete sample is controlled through the aluminium heating plate below the concrete sample. The heating plate prevents icing on the concrete surface. The temperature of the concrete surface during the test is approximately −2 °C which is sufficient to keep the surface ice free during ice movement. More detailed description of the abrasion rig is given in [1].

The abrasion of concrete was measure with laser scanner that had vertical accuracy of measurements of 16 µm, and gave a surface mesh with measuring point distance 1mm and 50 µm in x- and y- direction respectively. The scheme of the laser scanning is shown in Figure 1 (b).The new laser scanner allows topography studies on different concrete surfaces. The laser scanning method is described in details in [1].





(a) (b)

Figure 1 – (a) The scheme of concrete-ice abrasion test, (b) the scheme of the laser scanning.

2.2 Materials: concrete and ice

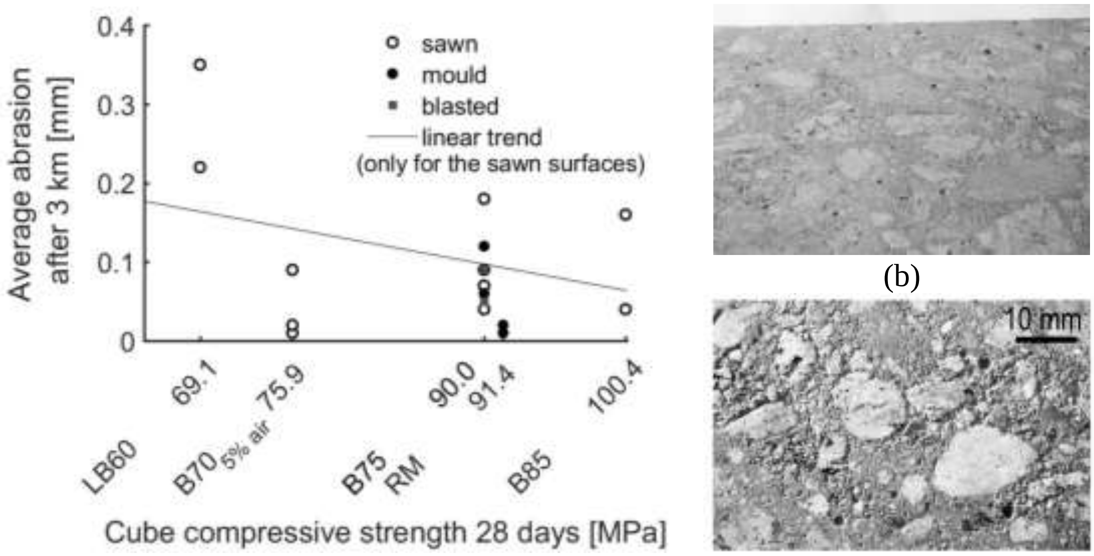
The concrete samples used for the concrete-ice abrasion test were slabs measuring 100 × 310 mm and 50 mm high, which were cured in water at + 20 °C for 11 months before the experiments.

High-performance type concrete for realistic offshore conditions were tested with workability and compressive strength similar to those of offshore concrete. Five concrete mixes were investigated: two Normal Density (ND) concrete mixes with different compressive strength (B75 and B85), a frost durable concrete mix with air entrainment (B70-5% air), lightweight aggregate (LWA) concrete with porous coarse aggregate (LB60), and repair mortar (RM). Besides the quality of the concrete mix the type of concrete surface was varied: sawn, moulded and sand-blasted during the concrete-ice abrasion tests. The test program included 17 samples (two parallel samples of each type).

In the experiments the concrete surface is abraded by fresh-water ice produced by unidirectional freezing. The ice samples had a cylindrical shape with a diameter of 73.4 mm and a height of 180 mm. The density of the ice is 917.0 kg/m^3 and porosity is less than 0.1%.

3. RESULTS AND DISCUSSION

The abrasion of tested concrete samples after 3 km as function of strength is shown in Figure 2. The highest abrasion was found for the sawn lightweight concrete mix and the smallest for the mould sample of the repairing mortar. The protrusion of both lightweight and normal density aggregate was observed on the sawn surfaces. Figure 2 (b,c) shows sawn surface B75 before the test and after with protruded granite aggregate. This happens presumably due to microscale abrasion starting in the interfacial transition zone (ITZ). The abrasion rate of lightweight aggregate is greater than that of normal-weight aggregate.



(a) (b) (c)

Figure 2 – (a) Concrete strength vs average abrasion after 3 kilometres of sliding distance (b) sawn surface B75 before the test, (c)sawn surface B75 after 3 km test.

The abrasion rate was not constant and decreasing with sliding duration. The abrasion rate of tested concrete samples as function of strength is shown in Figure 3 for each sliding kilometer. The maximum wear rate was found during the first kilometer of sliding and thereafter dropping down. This characteristic process of wear rate transition from severe to mild is discussed in [1]. To find the reason for it will require more research but a literature search in [1] revealed that such behavior has been observed also on other materials and wear types.

Topography studies of the laser scan data of the different abraded concrete surfaces showed that it could be primarily depicted as a process of valley formation. The valleys originate from air voids opening and cutting of peaks. Contacts between larger ice-asperities and smaller concrete-asperities can induce contact tensile stress in concrete limited by the ice strength and this is sufficient to fracture the concrete [1]. The roughness of concrete surfaces increases from 0.01 – 0.04 mm up to 0.08 mm.

Another interesting feature observed during testing was that the consumption of ice seemed to vary a lot. This project was aimed to perform concrete-ice abrasion experiments of different surfaces and materials at identical conditions. However, the appearance of ice spallation affected the ice consumption and brought some deviation in test results. During a test of one single concrete specimen, sometimes the consumption of ice samples varied between 10 and 45. This was caused by varying degrees of spallation of ice during the test and increased abrasion depth and coefficient of friction [1].

It was found that the coefficient of friction (COF) was not clearly correlated to the abrasion. It varied in the range 0.005 – 0.013 and 0.008 – 0.085 for kinetic and static COF respectively. Presumably, the stable and low value of the coefficient of friction can be explained by a thin water film in the contact area, which works as a lubricant. The lubricant can support the load if the thickness of the water film is greater than the surface roughness.

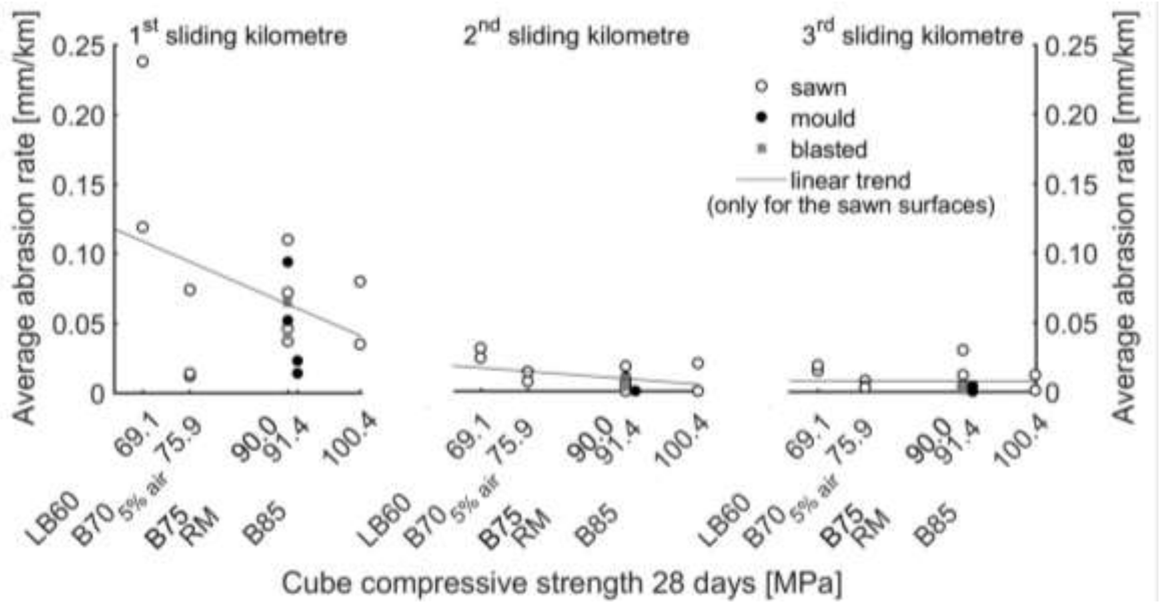


Figure 3 – Concrete strength to wear rate relation for each kilometre of sliding distance

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