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Ice abrasion of concrete, background theory and testing at the NTNU laboratory

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Abstract

Ice abrasion has been reviewed. Concrete and ice and their most important properties in accordance to ice abrasion have been studied. Concrete strength and contact pressure between ice and concrete is found to be important factors. Former studies of ice abrasion differ in their conclusions of which parameters they include in their ice abrasion models. The different parameters are; ice contact pressure, ice sliding speed, temperature, concrete strength, size of aggregate, total sliding distance. Different models include one or more of these parameters. Some of the previous experiments has come to different conclusions, possible reasons for these differences has been discussed.

A detailed description of the NTNU Ice Abrasion Laboratory is given. The abrasion test apparatus is based on the sliding contact abrasion test principle. A concrete specimen is mounted and an ice cylinder is slid on top of the concrete with applied pressure. Pressure, speed and temperature are all fully controllable to create different test scenarios. A custom made National Instruments LabView program is used to control, monitor and log the activities in the abrasion laboratory.

Ice abrasion testing has been done at the NTNU Ice Abrasion Laboratory, investigating a possible difference in abrasion rate for identical concrete with unlike initial treatment. A total of four concretes sample were tested. All four of them were saturated after this saturation period 2 of them was abrasion tested directly and 2 of them were dried, resaturated and then abrasion tested. Abrasion results were distorted by cracking of the concrete samples. No conclusive data on the abrasion rate were obtained. Two possible reasons for cracking of the concrete samples were found. The concrete samples have not been stored in best possible way before testing, which may have caused them to weaken. Secondly the ice abrasion machine has a weakness somewhere under the concrete sample. Either the concrete bedding its bearings or the load sensors yields during testing allowing the concrete to tilt up and down as the ice moves back and forth. Tilting of the concrete sample creates a bigger strain for the concrete at the turning point of ice cylinder. Measurers to remove this problem are discussed.

Acknowledgements

First I would like to give a big thank you to my supervisor Professor Stefan Jacobsen, who has supported me with his great knowledge and his patience with a slow-going student. Without him this thesis would not have been completed.

Big thanks for the aiding I have gotten from the technical personnel at the NTNU concrete laboratory, especially Steinar Seehus and Ove Lorass.

Thanks to Egil Møen who pioneered the ice abrasion lab at NTNU.

A thank you also goes to the guys at “Stålhjørnet” SINTEF for lending of digital indicator and coordinate table.

Thank you all!

Contents

Measurment excel file is digitally attached for particularly interested.

1. Introduction

1. Ice abrasion foreword

Ice is an obstacle for constructions of marine structures in cold regions. Abrasion on structures is a problem wherever there is moving ice. This is particularly in the arctic and sub-arctic areas. To understand the ice abrasion problem we need knowledge about the involving materials and their interaction. Ice and concrete properties are important factors to understand ice abrasion. Together with laboratory testing and field studies we can understand and predict ice abrasion problems. In order to increase this understanding NTNU has developed an ice abrasion test laboratory. This laboratory is used to find relations between abrasion depth in concrete and different test parameters. The variable parameters are concrete properties, ice properties, temperature, ice-concrete sliding speed and pressure between ice and concrete.

2. Why study ice abrasion on concrete?

Ice abrasion on concrete causes damage to structures which are exposed to moving ice. Continuous exposure will weaken the structure and can cause collapse if no measurement is taken. Ice abrasion is mainly a problem in the arctic and sub-arctic areas. In these areas harbors and offshore installations will be subjected to ice abrasion. As the need for fossil fuel goes up, more offshore installations must be built in the fossil fuel rich environment in the arctic/sub-arctic areas. In order to ensure that these structures can cope with the environment, ice abrasion data must be acquired. The abrasion has been studied in many different ways the last decades. For example, field investigations, computer simulations and laboratory tests. Many of these tests have not come to the same conclusions. The important factors of ice abrasion differ in different studies. These differences prove that further studying of ice abrasion is needed to fully understand the problem.

3. Limitations

In this master thesis I will limit my work to get to know the ice abrasion problem, describe the test apparatus and procedure, and do some basic abrasion experiments. A theoretical introduction to ice and concrete and their properties which are important for ice abrasion is necessary, together with a study and discussion of earlier ice abrasion studies and testing.

2. Background

1. What is ice abrasion?

Abrasion is the process of wearing down or rubbing away by means of friction. Ice abrasion is abrasion caused by ice. Abrasion rely on difference in hardness of materials, generally the hardest material will abrade the weakest material. However any two materials rubbing against each other will tend to abrade. If the process is repeated significantly many times a softer material will also abrade on the harder one. Ice abrasion typically will occur when drifting ice or an ice floe slides against a structure. This movement will cause friction between the structure and the ice and both the ice and the structure will be abraded. The amount of drifting ice is so large compared to the structure that it will abrade the structure even though the structure materials are much harder than the ice.

2. Ice

Basically ice is water frozen into solid state. Usually ice is the phase known as ice I_h, the hexagonal form of ordinary ice. Virtually all ice in the biosphere is ice I_h. This face occurs when liquid water is cooled below 0 degrees centigrade at 100 kPa or 1 atmospheric pressure. In nature ice appears in many forms, snowflakes, hail, icicles, glaciers, pack ice, floes, ridges and so on.

Ice is considered a mineral due to its naturally occurring crystalline solid with an ordered structure. The density of ice is less than the density of water, this is an unusual property. This makes ice float on water which is an important factor in the ice water sphere. Without this reduced density lots of the water on earth could have been frozen from top to bottom [2]. Ice density is about 10 % less than that of water, resulting in 90 % of the ice floating in water is beneath the waterline. The reduced density is a result of the dominating hydrogen bonding packing the molecules less dense. Less dense packing also results in increased volume when frozen. Increased volume is the cause of freeze- thaw weathering. In engineering freeze-thaw effect and ice properties together with ice movement are important.

i. Freeze-thaw weathering

Freeze-thaw weathering is the process of water freezing and thawing. When water freezes it expands with approximately 10 %. If water is kept enclosed when it freezes it will expand and force enclosure to become bigger. This process is most frequently in moist areas with fluctuating temperatures above and below 0 degrees centigrade. Alpine areas are subject of freeze-thaw actions. On land the arctic areas is not especially subjected to freeze-thaw actions due to constant temperature below 0, but in marine environment where the tides moves up and down freeze-thaw action is expected. This is due to the tides going up and down, when the tide move up the water thaws the ice and refills it water. When the tide goes down again the structure is frozen down again in the cold climate.

ii. Ice mechanical and physical properties

Ice properties are very useful when calculating ice actions on structures. The mechanical properties of ice have been studied for many years. Reliable data about physical properties and strength parameters has been acquired. The physical and mechanical properties we need knowledge about to predict ice action is:

- Compressive strength
- Tensile/flexural strength
- Elastic modules
- Fracture toughness
- Shear strength
- Density
- Salinity
- Hardness

The compressive and tensile strength of concrete varies with temperature and reaches for 5 -25 MPa compressive and 0.7 - 3.1 MPa tensile over the temperature range of -10 to – 20 degrees. Generally the strength of ice increases with decreasing temperatures in both tension and compression.[3]

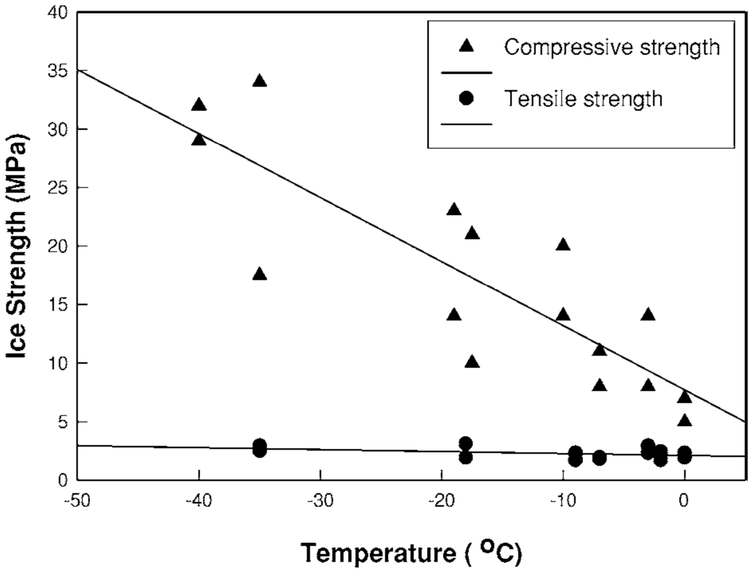

Figure 1 - Tensile and compressive strength of ice as a function of temperature[3]

Ice elastic modulus at a temperature of – 10 degrees ranges for 9.7 – 11.2 GPa Young's modulus and 0.29 – 0.32 Poisson's ratio.[3]

Fracture toughness of ice is in the range of 50 – 150 kPa $m^{1/2}$, this is roughly one-tenth of fracture toughness of glass.[3]

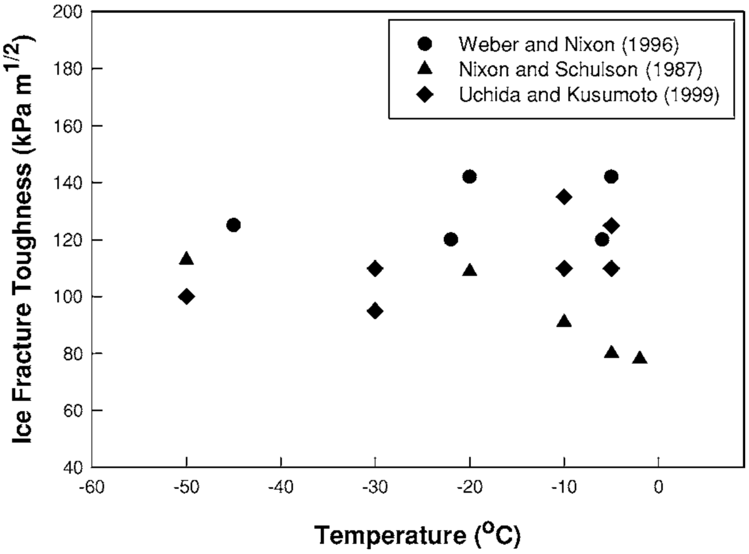

Figure 2 - Fracture toughness of ice as a function of temperature[3]

Salinity of the ice influences the strength of the ice. Generally the higher salinity the lower the ice strength.[4]

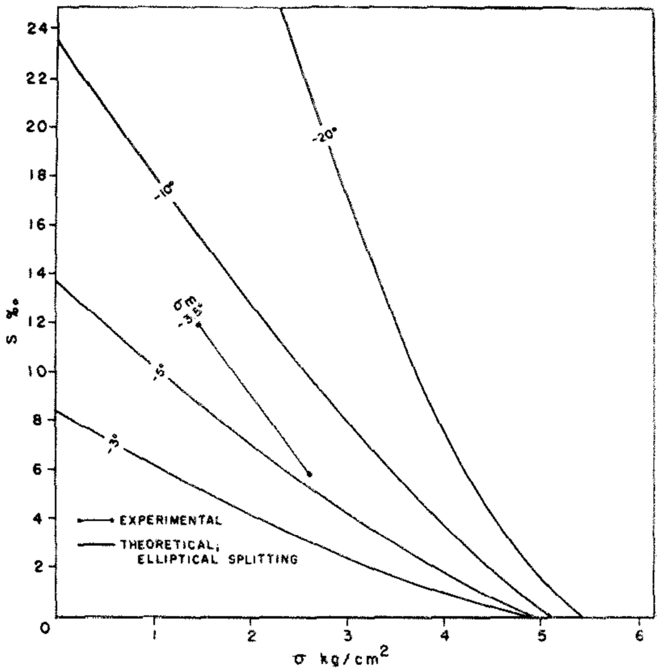

Figure 3 - The relation between tensile strength and salinity at various temperatures for elliptical splitting[4]

Hardness of the ice is also an important for the abrasion rate. Harder ice creates more abrasion. Hardness of ice varies as a factor of loading time and temperature. Longer loading times reduce hardness of the ice. Lower temperatures increase hardness of ice.[5]

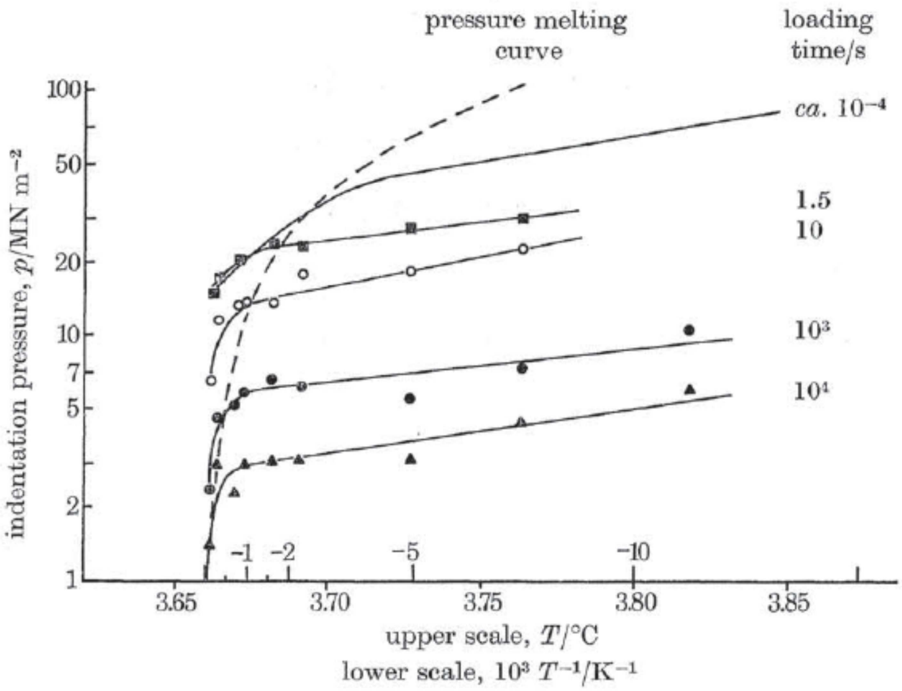

Figure 4 - Indentation hardness of polycrystalline ice as a function of absolute temperature for various loading times.[5]

iii. Ice movement

Moving ice is a big contributor to all the ice action on structures, except from freeze-thaw weathering. Ice movements differ hugely around the globe. The main forces behind ice movement at sea are sea currents and wind. To predict the ice movement in an area we need good data on wind and current. The current and wind can differ a lot even within one sea[6]. Exact data from the planned construction site is necessary to understand the ice movement in the area.

3. Concrete

Concrete is a composite material, composed of cement and other cementitious materials such as fly ash and slag cement, aggregates, water and chemical admixtures. The aggregate is generally made of gravel or crushed rock and finer particles such as sand. [7]

Concrete hardens if mixed with water and is allowed to lay still. This hardening process is a chemical process called hydration. During the hydration water reacts with the cement and binds all the other concrete components together.

Concrete is the most used man-made material in the world.[8] There are many types of concrete available, and if you are going to construct something special you could design your own concrete just for that purpose. By varying the proportions of the different concrete ingredients you vary the concrete properties.

Concrete properties like strength, density, reaction speed, reaction heat development, frost resistance, coefficient of thermal expansion, permeability can all be adjusted to fit your construction requirements as best as possible. Two of the most important concrete properties which create resistance to ice abrasion are concrete strength and frost resistance. High concrete strength and good frost resistance together with good bonding between cement paste and aggregate gives good ice abrasive resistance. [9]

Concrete strength is influenced by:

Compaction, compaction is driving the air out of the concrete. Good compaction gives a denser concrete which is stronger.

Curing, keeping the concrete under controlled temperature and in humid conditions will allow it to reach maximum strength.

Type of cement, different types of cement gives different strengths.

Water cement ratio, the less w/c the stronger the concrete, if other variables is kept the same.[10]

To make high strength concrete producers select high quality portland cement, optimize aggregates and optimizes the combination of material proportions cement, water, aggregates and admixtures. Aggregates for high strength concrete is selected by strength, size, bond between cement paste and aggregate and the surface characteristics.[11]

Frost resistance of concrete is mainly determined by the air content. Higher air content gives better frost resistance. With more pores the water in the concrete has more space to expand to before damage to the concrete is unavoidable. Proper use of micro silica will also increase frost resistance. Micro silica gives an improved pore stability which gives a more effective pore structure to reduce freeze-thaw damage.[12]

Concrete changes strength and strain properties during freeze-thaw cycles. The fatigue strength of concrete is also reduced due to freeze-thaw cycles. In ordinary cement concretes bond strength at the concrete surface is reduced faster than compressive or tensile strength. Concrete containing silica and blast furnace slag withstand freeze-thaw cycles best. Concrete subjected to freeze-thaw cycles and ice abrasion at the same time may abrade more than with just ice abrasion. Below is a figure showing the strength loss due to freeze-thaw cycles. Values after 0, 25 and 50 cycles is given. [13]

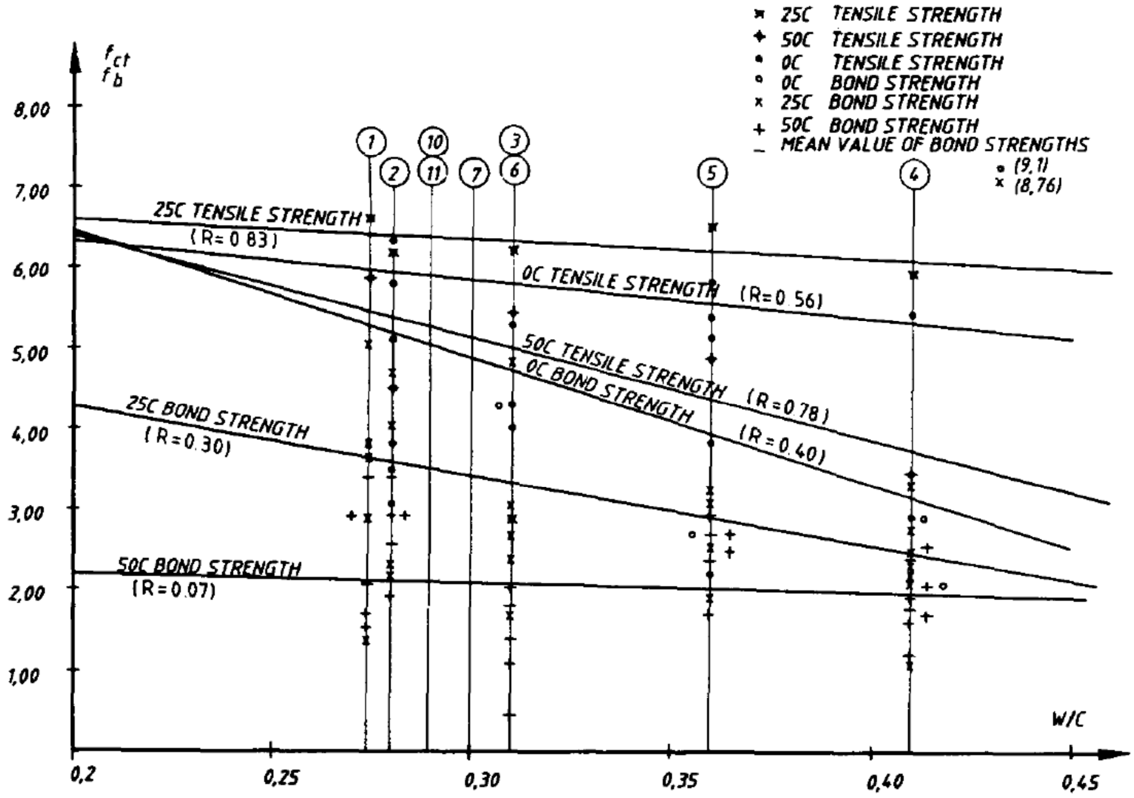

Figure 5 - Flexural tensile strength of concrete and the bond strength of aggregate stones as the function of w/c ration and number of freeze-thaw cycles.[13]

Good bonding between cement and aggregates is generally obtained with higher strength of the concrete. Better bond between aggregate and cement gives higher concrete strength.[11]

4. Ice abrasion on concrete, the mechanism

The abrasion on concrete can be divided into three steps.[14]

Step a: abrasion of the cement paste.

Step b: abrasion of the cement paste and the loosening of aggregates

Step c: abrasion of concrete paste and removal of aggregates which has become so loose that the bonding between the cement and the aggregate is weaker than the friction forces.

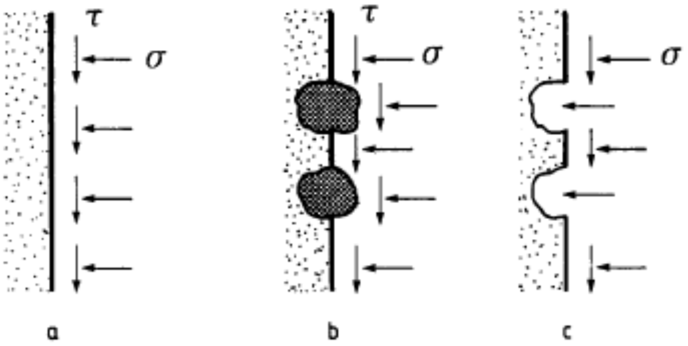

Figure 6 - Ice abrading mechanism a - c[13]

Ice pressure, sliding direction and friction between the concrete and the ice affects the rate of abrasion. Higher pressure gives more abrasion. Ice sliding parallel with the surface of the structure causes more abrasion than ice moving straight onto the structure. Higher friction gives more abrasion. Abrasion of the surface tends to give a higher friction coefficient against the ice. Abrasion may therefore go faster after the smoother outer layer has disappeared[14].

3. Methods

To predict the abrasion of concrete it has been done both laboratory- and field testing. These results have been used to create models for calculating ice abrasion.

1. Laboratory testing

Laboratory testing of ice abrasion main principle is to move concrete and against each other and create friction and also create pressure between the two materials. In 1995 Hara made a suggestion to which conditions an ice abrasion apparatus should be able to simulate. They were the following[1].

- Different contact pressure, ice temperature and relative velocities
- Both static and kinetic friction during the same test
- Easy and accurate measurement of the abrasion amount
- Prevent melting of ice due to frictional heat
- Allow for easy removal of ice and concrete shavings on the specimen surface
- The coefficient of friction between the ice and concrete must remain constant
- The test results should be as realistic as possible so they can be used as basis for predicting the wear rate for real structures exposed to ice abrasion

He also divided the different testing apparatuses into four different categories based on their test method basics.

- Relative abrasion test
- Revolving disc test
- Tumbler abrasion test
- Sliding contact abrasion test

i. Relative abrasion test

The relative abrasion test was developed by ABAM Inc. in cooperation with other companies in the same development program. The principle design of this abrasion test is a round concrete specimen rotating between two blocks of ice. The concrete rotated at 100 – 500 rpm and the pressure between the ice and the concrete is 0.21 – 0.34 MPa. Mentioned weaknesses with this test where, only kinetic friction, too high rotating speed, friction heat may create an ice film on the concrete specimen and the ice contact area increases over time reducing the effective pressure.

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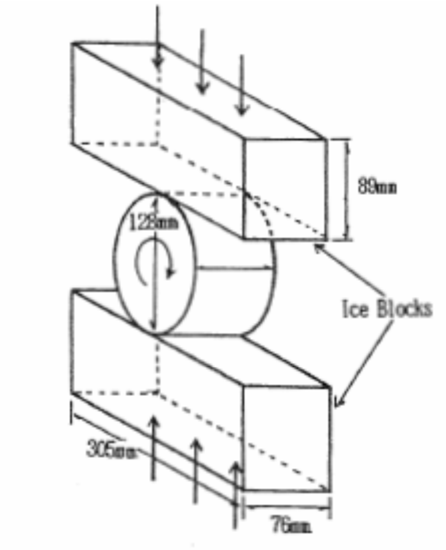


Figure 7 - Principle sketch of the relative abrasion testing[1]

ii. Revolving disc test

This test was also developed by ABAM joint industry project. The principle of design in this test is a hollow concrete cylinder mounted on a rotating disc. The rotating concrete is forced against a circular ice sheet. Contact pressure in this test is 0.45 – 0.98 MPa and the rotation speed resulted in an ice concrete velocity of 77 cm/s. Others has also developed test apparatus using the revolving disc system, but none of them where used directly for ice abrasion testing.

Mentioned weaknesses with this test where, only kinetic friction, variable relative velocity due to circular concrete specimen and a possibility for ice growth on the concrete surface.

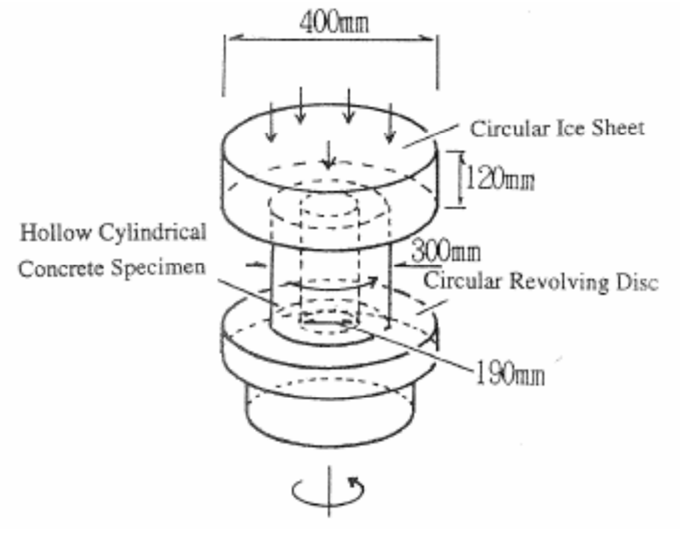


Figure 8 - Principle sketch of the revolving disc abrasion test[1]

iii. Tumbler abrasion test

Tumbler abrasion test is another ABAM test. The principle of design in this test is a cylindrical concrete container which rotates. To test abrasion the container is filled with ice, coarse aggregates and aluminum oxide grit. This test does not produce data relevant for the ice abrasion made by moving ice sheets.

iv. Sliding contact abrasion test

The sliding contact abrasion test has been developed at used by different people and firms. All based on the same basic design, sliding concrete against ice. The ABAM sliding abrasion test project uses a cylindrical concrete specimen sliding with a 20 degree arc over the ice block. The sliding speed and vertical force spanned between 10.1 – 20.2 cm/sec at 1.72 MPa. Another test apparatus developed by Saeki uses a trapezoidal concrete specimen which slides back and forth over a stationary ice block. Possible sliding speeds is 2, 5 and 20 cm/sec and contact pressure could be varied from 0 – 70 MPa. The ice abrasion apparatus at NTNU is also a sliding contact abrasion test. The basic concept is the same but at the NTNU laboratory the ice is slid against a stationary concrete specimen. This abrasion test will be described thoroughly in chapter 2 Ice abrasion testing at NTNU.

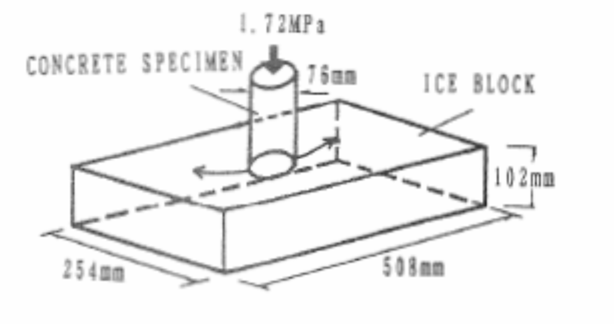


Figure 9 - Principle sketch of the sliding abrasion test

2. Field testing

The abrasion on concrete has also been tested out in the field. These studies were done at sea with an icebreaker. A concrete specimen was mounted onto the bow of the icebreaker and abrasion was measured after a given distance. Maximum abrasion was found at the lower part of the specimen. The result after 40 km with concrete strength between f_c = 30 - 60 MPa varied between 2 - 15 mm.[15]

3. Field studies

Field studies of ice abrasion are the most reliable data you could obtain about ice abrasion. Accurate data on the ice abrasion from that exact location can easily be found. To use these data to calculate the probable abrasion on another structure another place you need good data on the ice conditions. Without ice condition data from both study location and planned structure location experience from the study cannot be used in a proper manner.

Different studies have been done in Canada, Japan and the Gulf of Bothanica. In Canada studies have been done both on bridge pier and in docks. The Japanese studies contains of bridge piers. In the Gulf of Bothanica there have been several studies of lighthouses. The abrasion differs a lot from place to place and year to year. Different ice conditions each year contributes heavily to these differences.

The field study of lighthouses gave some knowledge about ice abrasion. Ice conditions means more to abrasion than the concrete properties. Increased abrasion depth further north due to more severe ice conditions. No abrasion occurred where the level ice never exceeded 0.3 meter.

The studies in Japan confirmed that abrasion increases with more severe ice conditions, increased ice velocity and pressure. The abrasion was largest at the waterline which is in good correlation with the icebreaker tests done.

4. Results from previous studies, discussions

i. Abrasion test with cylindrical ice at NTNU laboratory, effects of difference in ice sliding distance.

At NTNUs test laboratory an ice cylinder is used during the tests. This will cause the effective sliding distance to differ over the specimen. The cylinder has a diameter of 74mm. In the center the effective distance will then be 74mm divided by length of travel. At NTNUs test laboratory this is 200 mm. So the effective sliding distance in the center of the concrete is 74/200 = 0.37. This means that for every meter the test machine runs the concrete is only “feeling “ 0.37*1 meter wear which is 0.37 meter. To run 1 km effective sliding the machine has to run 1000/0.37 = 2702 meters. This only applies in the center of the cylinder. The further away from the center we go the effective abrasion distance is smaller. When measuring abrasion mechanically with a digital indicator the concrete specimen is given a coordinate system as shown in figure 10. X = 0, 5mm into the concrete sample. Y = 0 in the center of the concrete. During the test the ice cylinder is forced back and forth in the y direction. The center of the cylinder moves from y=-100mm to y=100mm.

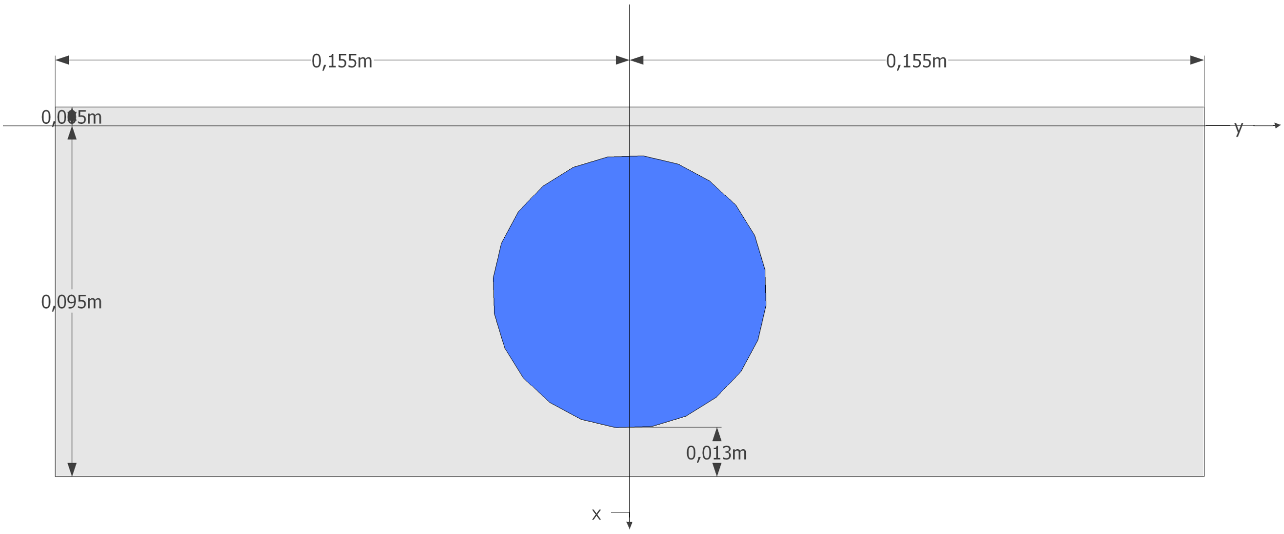


Figure 10 - Principle sketch showing abrasion measurment coordinate system. Grey concrete specimen with blue ice cylinder in the center.

Measurements in x-directions begins in x=0 and then stepwise with 10 mm steps until x=90
Measurements in y-directions begins in y=-100 and then stepwise with 20 mm steps until y=100
Following table shows an example on how a measurement grid looks like.

	x=									
y=	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
100										
80										
60										
40										
20										
0										
-20										
-40										
-60										
-80										
-100										

Table 1 - Measurment grid example

The effective sliding distance is 1 in the center. Table 2 shows how the effective sliding distance becomes smaller away from the center.

x-coordinate	Distance From center	Circle Radius	Distance from center to circle	Effective distance Chord length	Effective Distance factor
0	45	37	0	0	-
10	35	37	12,0	24,0	0,3
20	25	37	27,3	54,6	0,7
30	15	37	33,8	67,6	0,9
40	5	37	36,7	73,3	1,0
50	5	37	36,7	73,3	1,0
60	15	37	33,8	67,6	0,9
70	25	37	27,3	54,6	0,7
80	35	37	12,0	24,0	0,3
90	45	37	0	0	-

Table 2 - Calculations of effective distance/chord length

Formula for calculation, example at 15mm from center:

$$\cos\left(\sin^{-1}\left(\frac{15}{37}\right)\right)37$$

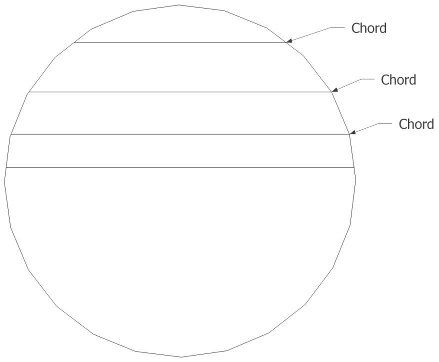


Figure 11 - Principle sketch chord

With this in our minds we now look at the abrasion profiles from previous results from testing at the NTNU ice abrasion laboratory. The following abrasion data is found by Egil Møen. Concrete type and properties is irrelevant in this discussion. Abrasions are measured after 5 km effective sliding. From previous pages we know that that only is true for the center, x=40 and x=50.

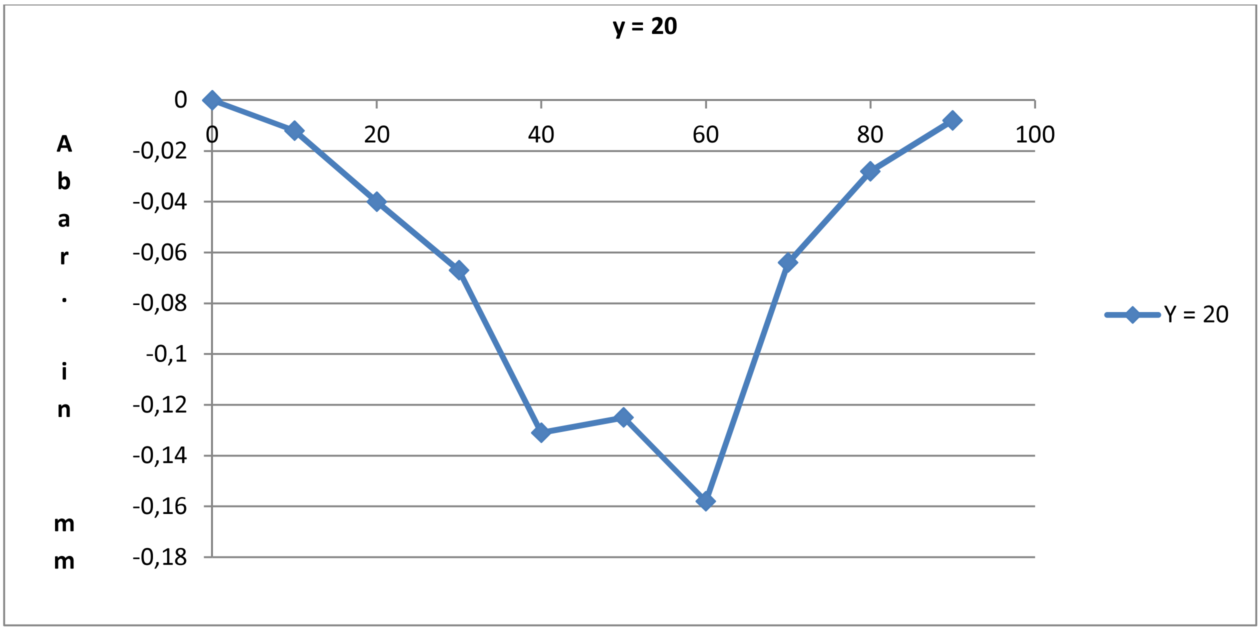


Figure 12 - Abrasion profile y = 20

If the results further away from the center is multiplied so the effective distance is the same for points. Theoretically if the abrasion is linear in terms of sliding distance and all other factors such as pressure and temperature is constant over the circle cross-section, we should get a straight line.

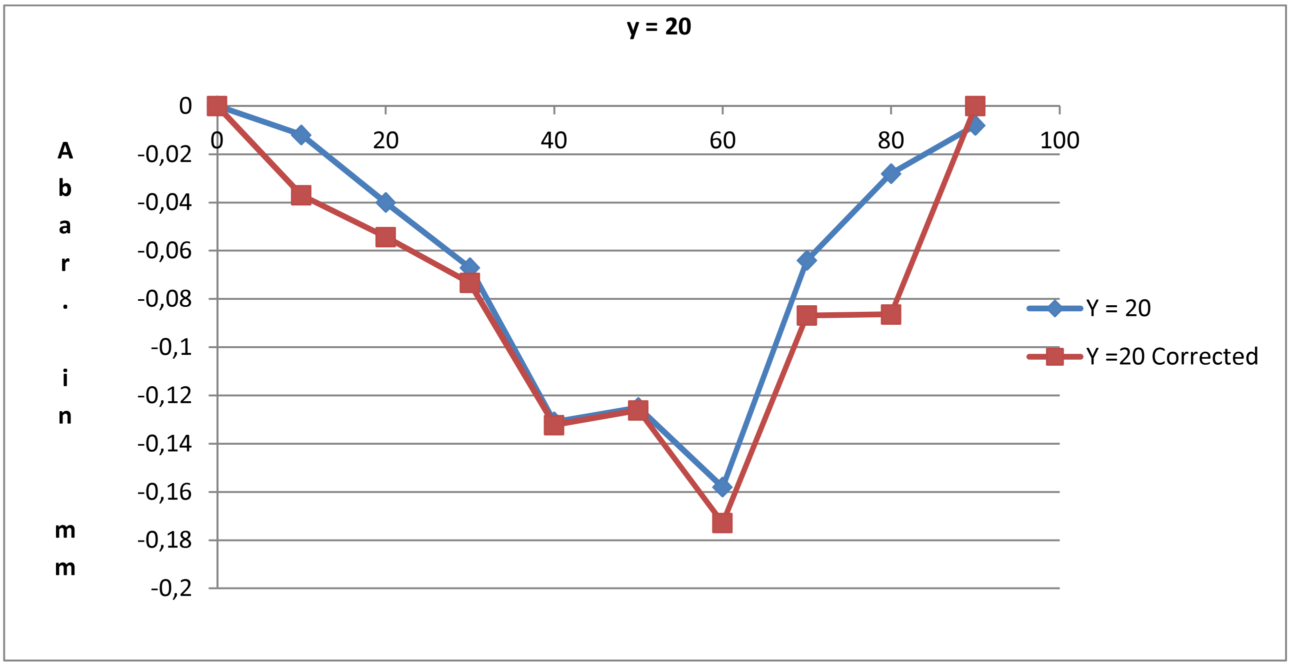


Figure 13 - Abrasion profile y = 20 corrected for difference in effective distance

Figure 14 shows both the corrected abrasion depth and the measured abrasion depth. As we can see the corrected red line is not straight, but profile is not as V-shaped as the original curve. If we remove the points x=0 and x=90 which is outside the abraded area, the results looks better even though it is the same data.

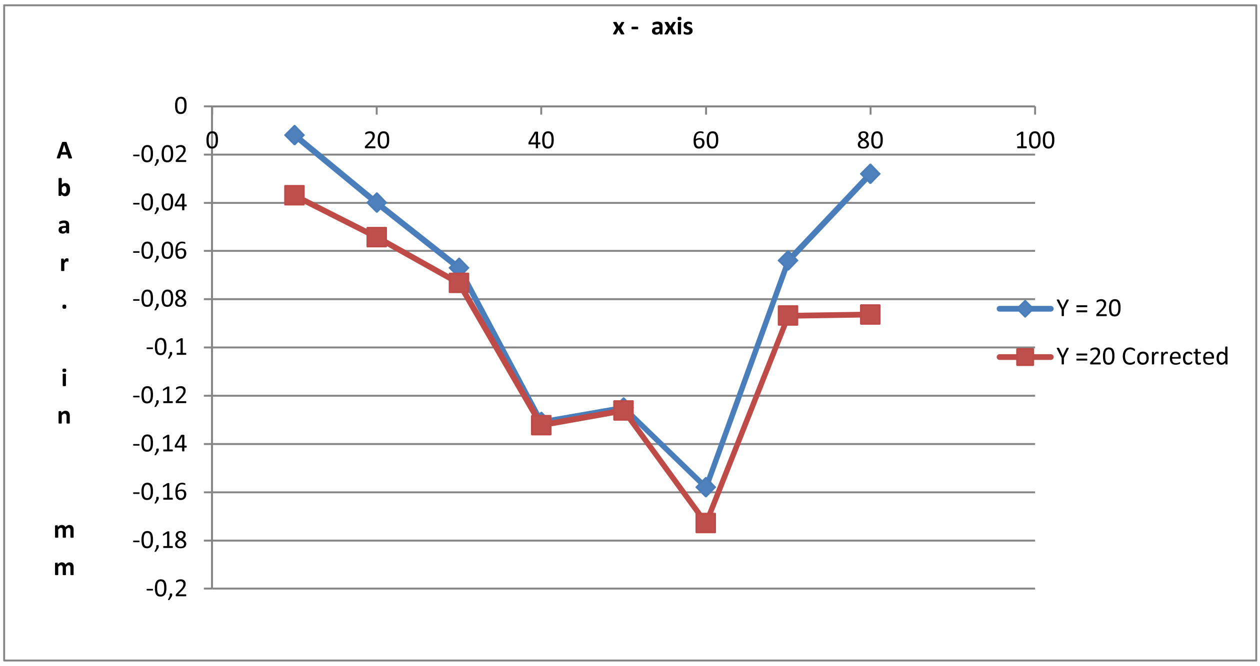
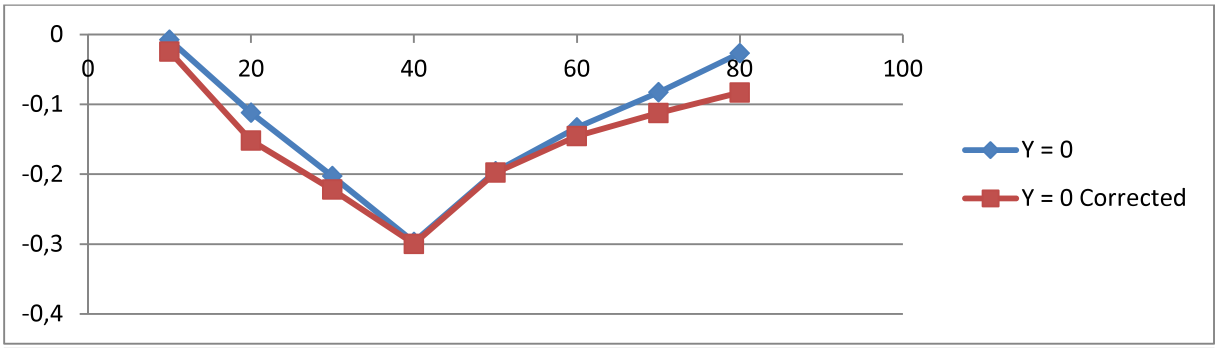
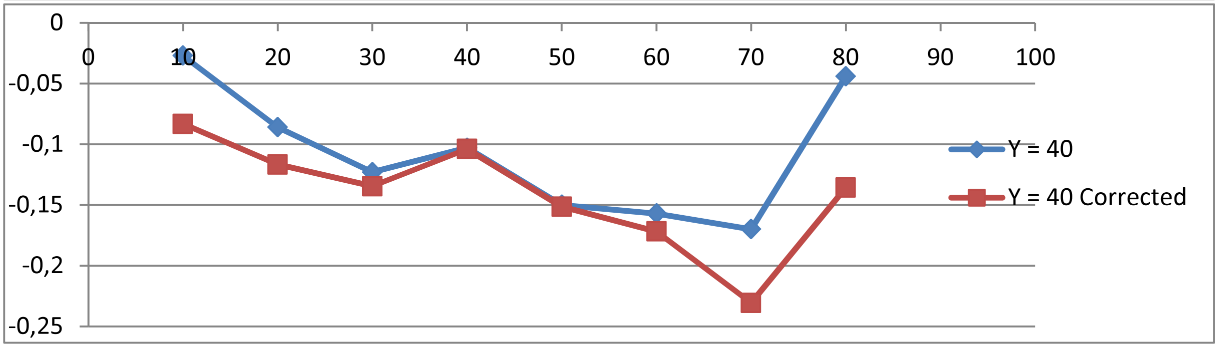


Figure 14 - Abrasion profile y = 20 corrected for difference in effective distance (without the datum points a x= 0 and x = 90)





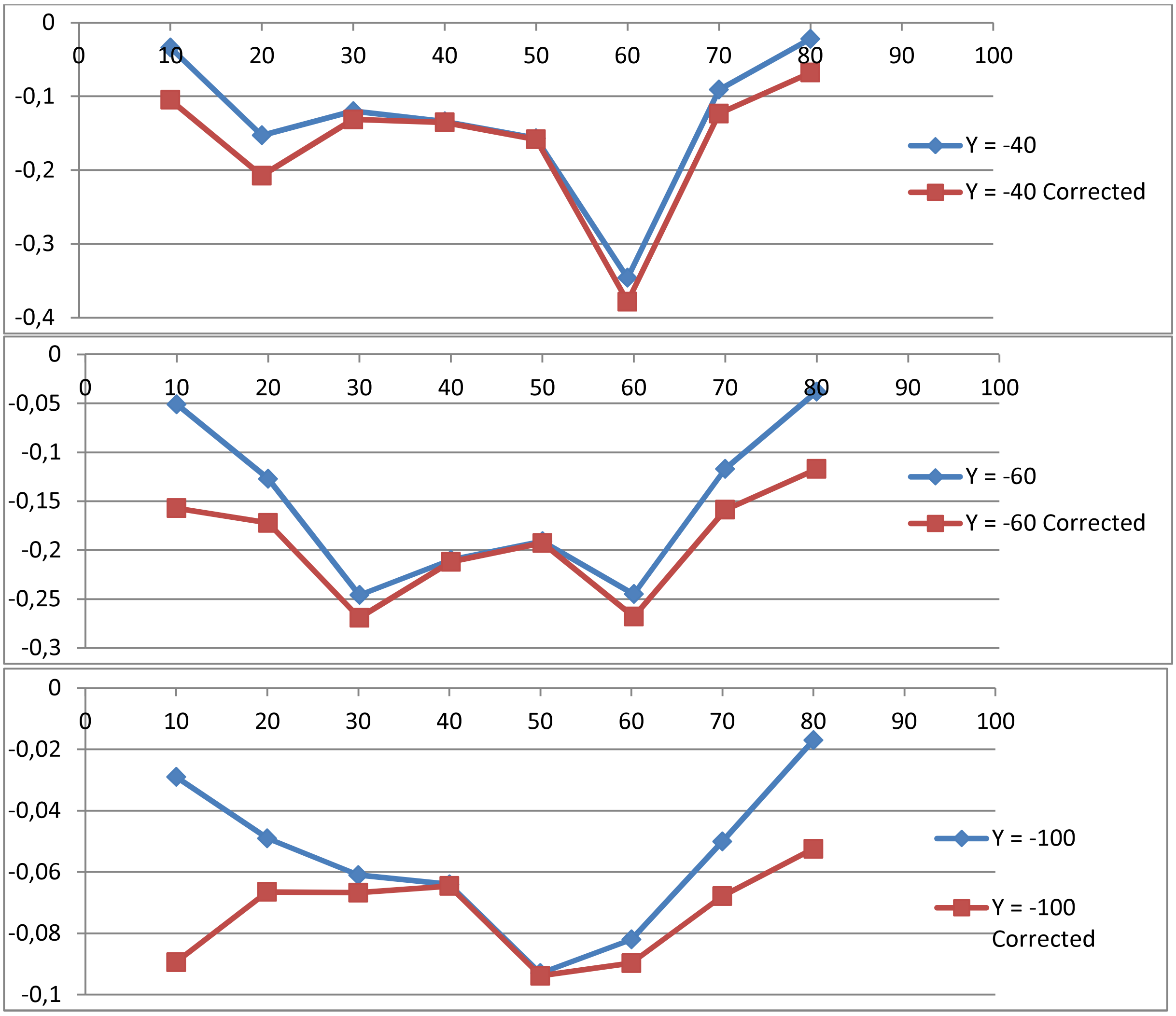


Figure 15 - Five different abrasion profiles corrected for difference in effective distance (without the datum points a x= 0 and x = 90)

In figure 14 and 15 we saw 6 different abrasion profiles with corrections showed. All with x=0 and x=90 removed. The results differ from profile to profile, some of them show a pretty straight corrected line. Others do not. Hence no obvious conclusion can be made from these data. By correcting for effective distance the abrasion becomes more linear, but not at all perfect. This leads to believe that other factors also differ when we move away from the center of the sample. Unevenly distributed pressure may be one reason that we see that abrasion tends to be highest in the middle even when difference in sliding distance is corrected for. Taking this into consideration abrading with a quadratic ice specimen could be beneficial.

ii. Differences in previous test results

Abrasion testing has been done different places in the world, mostly in areas where ice actions is present. Studies have primarily been made in Finland, Russia, Japan, Canada and Norway. When taking a closer look at some results from Russia and Japan, quite opposite conclusions has been made.

Abrasion results from Russia originates from the test rig in figure 16.[16]

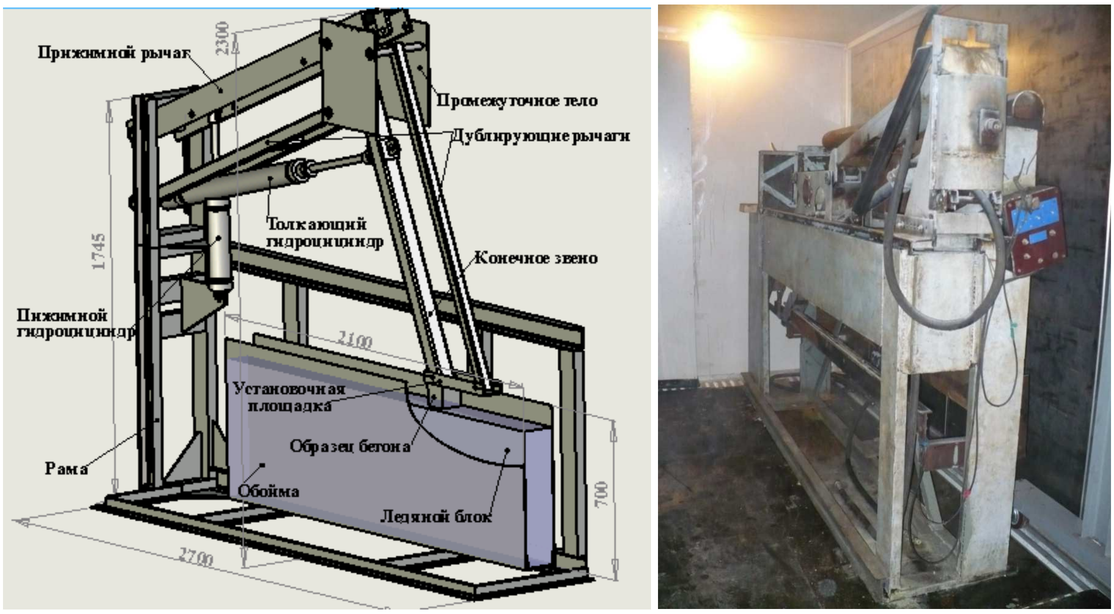


Figure 16- Principle sketch and picture of Russian ice abrasion test rig[16]

This abrasion test setup slides a small concrete specimen on to a big chunk of ice. This chunk of ice is either gathered from the sea ice in the ocean or made at the laboratory.

At the Hokkoaido University in Japan the test rig in figure 17 is used.

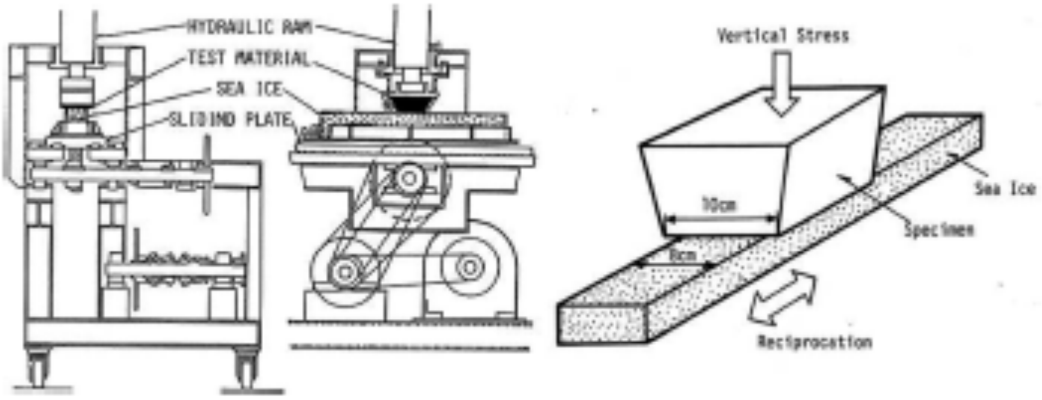


Figure 17 - Princicple sketch of Japanese test rig[17]

Both rigs use sliding contact abrasion. Even though the principle of these two test rigs is very similar the results coming from the test seem to differ.

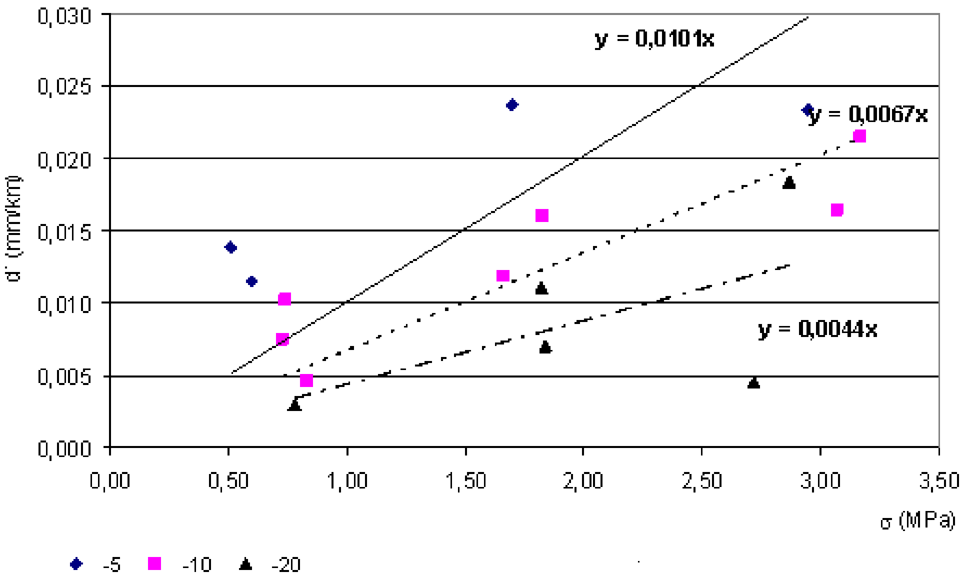


Figure 18 - Variation of specific abrasion depth depending on temperature and contact pressure, results from Russian testing.[16]

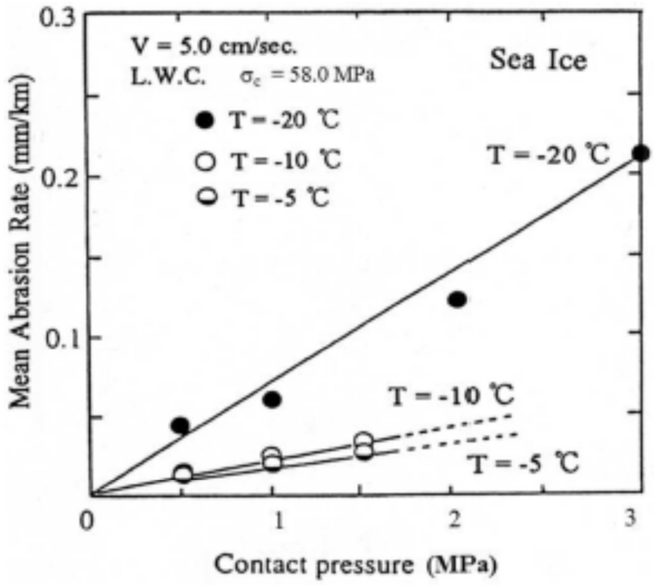


Figure 19 - Variation of specific abrasion depth depending on temperature and contact pressure, results from Japanese testing.[17]

Both tests show that higher contact pressure gives higher abrasion rate. This is acknowledged and well known. Looking at the abrasion rate on different temperatures the two tests concludes opposite. In the Russian test abrasion rate decreases with lower temperatures, reverse of what you would expect due to ice strength increasing at lower temperatures. In the Japanese test abrasion rate increases significantly when temperatures drop below -10 °C. The two tests finds opposite results, with test equipment using the same principle of testing. What is the reason of these opposite results?

In the Japanese tests an air blower is used to blow away abraded ice and concrete from the surface, this air blower is also used to cool down the ice.[17] Concrete temperature in this setup could be different from the ice temperature. In Russia temperature is fixed in the lab, making concrete and ice temperatures the same. Concrete surface temperatures below 0 °C can cause add-on freezing on the concrete. If ice melts due to pressure and friction heat it can refreeze on top of the concrete and create a thin ice layer. This thin ice layer will protect the concrete from abrasion. The friction between the concrete and the ice will be significantly reduced causing abrasion rate to decrease. In the Japanese test where concrete and ice could have different temperatures there will be no add-on freezing if the concrete temperature is kept above 0 °C. This will cause colder stronger ice to abrade more than warmer weaker ice.

In a real world situation most ice abrasion happens in a water environment. It is reason to believe that in the contact zone between ice and concrete water will appear, reducing the chance for add-on freezing on the concrete structure. Based upon this assumption the Japanese test results will be more real world comparable.

5. Calculation models for ice abrasion on concrete

By combining testing and field studies models for determination of abrasion on concrete has been made. An overview of the different models is given in table 3.

Developed by	Formula	Parameters	Comments
Itoh, Y.[18, 19]	$S_r = p(9.708T^2 + 1295.7) * 10^{-6}$	S_r = rate of abrasion [mm/km] P = ice contact pressure [kgf/cm^2] T = ice temperature	Only considering ice temperature and contact pressure
Hanada, M[20]	$S = S_r * \sigma_v * L$	S = Total average abrasion depth [mm] S_r = Abrasion rate of the exposed material [mm/km/MPa] σ_v = Contact pressure between ice and structure [MPa] L = Total sliding distance of the ice [km]	Much alike Itoh's formula pluss taking account for abrasion rate for exposed material
Hara, F. [21]	$S = 0.0012 * \sigma_v$	S = rate of abrasion [mm/km] σ_v = ice contact pressure	General based on one concrete and one ice condition
Janson, J. E.[22]	$Abrasionrate = \int 0.0015vsdt$	v = ice drift velocity [knots] s = ice thickness [mm] t = time [days]	Ice thickness and ice velocity the two governing parameters
Huovinen, S. [15]	$ABR = \sum_{i=1}^{n} a_i \frac{\lg n_s}{\lg n_1} R_i + (1 - \sum a_i) b$	ABR = Abrasion depth [mm] a_i = proportional volume of aggregate stones with radius R_i $\sum a_i$ = total proportional volume of aggregate stones in concrete n_s = number of ice impacts during ice sheet movement n_1 = number of ice impacts when $L_{cr}/R = 1$ b = abrasion rate of cement paste [mm] L_{cr} = crack length [mm] R_i = radius of aggregate stone [mm]	Abrasion with loosening of aggregate stones and cement paste abrasion. Figure 8 gives results with this formula.
Huovinen, S.[15]	$ABR = \frac{1}{(1 - \sum a_i)} \frac{3}{f_c} s$	ABR = Abrasion depth [mm] $\sum a_i$ = total proportional volume of aggregate stones in concrete f_c = compressive strength of the concrete[MPa]	Abrasion depth when the bond strength between aggregate stones and the cement paste is so weak that the stones loosen during the first ice impact.

Table 3 - Models for calculations of ice abrasion

In figure 20 we can see the results from calculations of abrasion depth as function of ice movement for different concrete strengths using the last model in table 3.

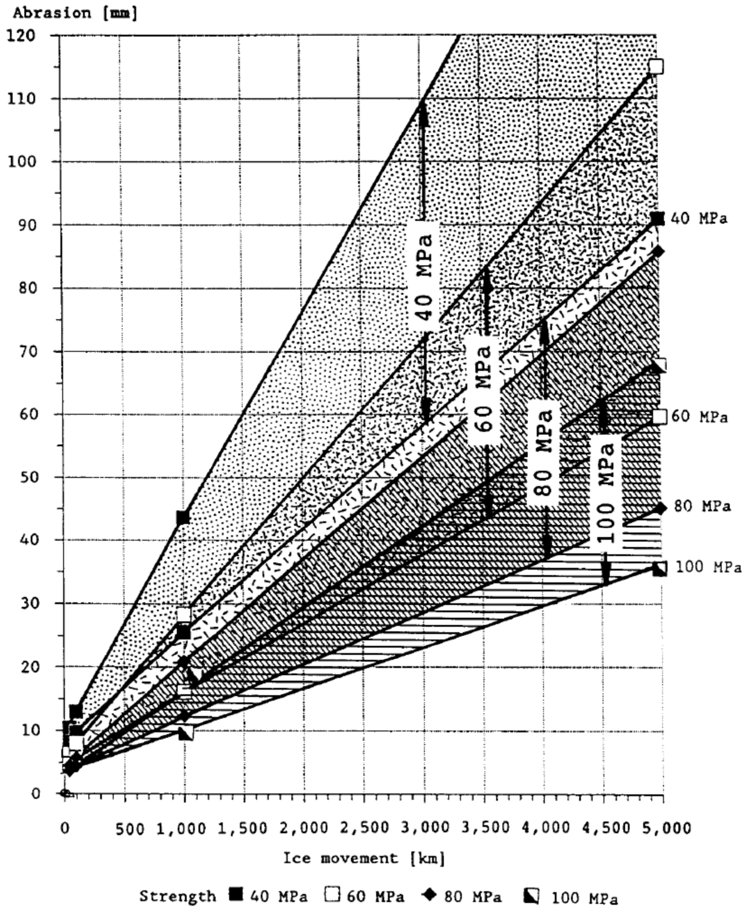


Figure 20 – Example of abrasion calculations for concrete strengths fc= 40, 60, 80 and 1000 MPa as the function of ice movement[15]

2. Ice abrasion testing at NTNU

1. The laboratory

i. Room

The ice abrasion lab at the department of structural engineering is a small insulated room specially made for ice abrasion testing. The room is equipped with an industrial cooler which can maintain room temperature of -20 degrees centigrade. Low temperature is essential for ice testing or else ice will melt instead of keeping its intended form. It would be possible to just cool the ice and the concrete specimen to the wanted temperature, but this will give an unwanted effect melting the ice causing water flowing around in the lab. Cooling of the entire room has the positive effect of keeping the ice cold and dry even after being abraded on the concrete. Therefore the room is kept at temperatures below freezing during test periods.

ii. The ice abrasion rig

The ice abrasion rig contains of 3 major components; (1) the machine creating the horizontal movement, (2) an insulated cylinder for the ice specimen connected to an engine which creates the vertical pressure and (3) bedding for the concrete specimen. A refrigerated/heating circulator, a julabo, is also connected to the test rig. Detailed description and figures follows.

1: An old metal plane machine creating the horizontal movement of the ice over the concrete. This machine has been modified to its purpose and is computer controlled through an especially made program in LabView. The machine is connected to a draw wire distance recorder which reports to the same program in LabView. In the computer program you can adjust the engines revolutions per minute. The higher the rpm the higher the horizontal sliding speed becomes. The in the moment speed and the average speed of the machine reads out and gets recorded in the program thanks to the draw wire distance recorder. Total distance is also recorded.

Figure 21 - NTNU Ice abrasion apparatus, the grey metal plane machine

2: The part in figure 22 (not the grey part on the left) is an insulated cylinder with a piston in the top. The insulated cylinder's inside is made of cobber; this cobber cylinder has flow circuit connected to the Julabo. When removing the ice, heating is applied to get rid of all the ice rests. The piston pushes down through the cylinder creating vertical pressure down on the concrete specimen. The vertical pressure engine is computer controlled via LabView. The engine speed is also controlled to keep assured that the pressure is as constant as possible. This whole part is mounted on the plane machine and moves horizontally over the concrete specimen.

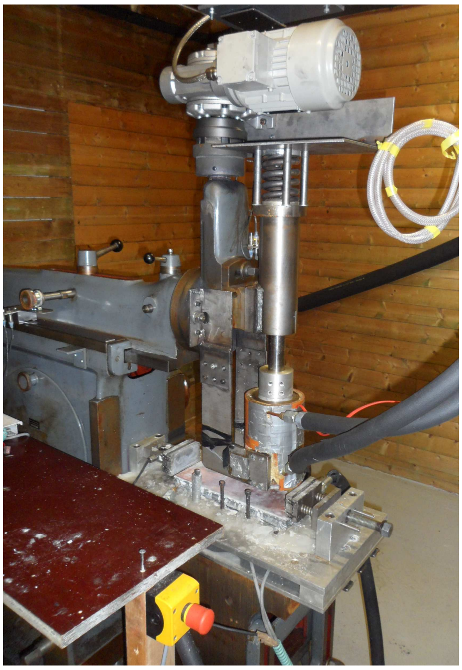


Figure 22 - NTNU Ice abrasion apparatus, insulated cylinder and vertical pressure engine

3: The bedding is mounted to ground and keeps the concrete specimen at a fixed position. Six bolts hold the concrete specimen in position perpendicular to the ice movement. In the ice movement direction a pretension system is used to hold the specimen in place. This pretension system includes a pressure sensor which reports to LabView. With this pressure sensor it is possible to read out the friction between the ice and the concrete. The concrete lies on a copper plate which has flow circuit connected to the Julabo, this is used for controlling the concrete temperature. Copper has a very high thermal conductivity, about 400 W/mK. High thermal conductivity results in fast heat transfer to the concrete specimen. The concrete temperature at the surface is important to control, if it is too cold the ice will freeze on top of the concrete and create a layer that protects against abrasion. Too warm concrete will melt the ice fast. A concrete specimen with 3 temperature sensors casted inside is used to find the right temperature in the copper bedding. Underneath the cobber plate lies two pressure sensors together these two reports the vertical pressure from the ice.

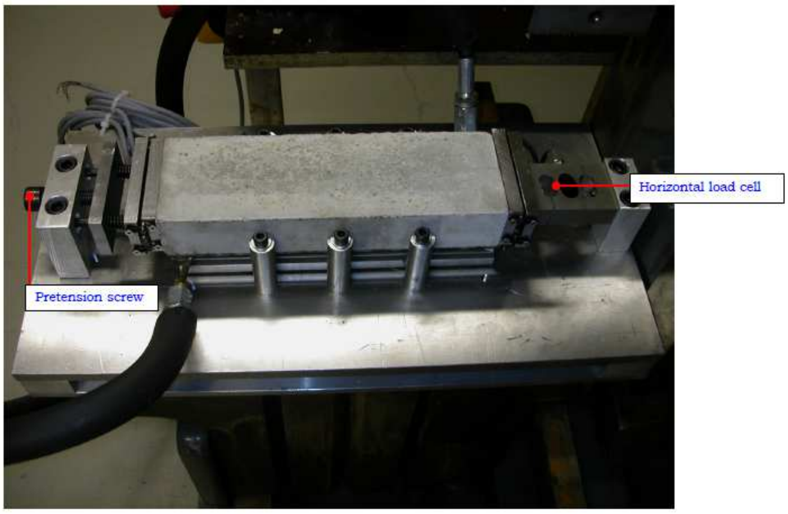


Figure 23 - NTNU Ice abrasion apparatus, concrete bedding

iii. Computer software, LabView

National Instruments LabView is used for controlling and logging data in the NTNU abrasion laboratory.

What is labview:

"LabVIEW is a graphical programming environment used by millions of engineers and scientists to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart. It offers unrivaled integration with thousands of hardware devices and provides hundreds of built-in libraries for advanced analysis and data visualization – all for creating virtual instrumentation. The LabVIEW platform is scalable across multiple targets and OSs, and, since its introduction in 1986, it has become an industry leader."[23]

The LabView program at NTNU abrasion laboratory is programmed to control all parts of the ice abrasion machine except from the Julabo and the room cooler.

Function	Controllable by LabView	Logged by LabView
Horizontal speed	Yes	Yes
Auto stop after given ice sliding distance	Yes	Yes
Vertical pressure ice/concrete contact pressuere	Yes	Yes
Speed of vertical pressure adjustment	Yes	Yes
Auto adjust to keep constant vertical pressure, to high and to low	Yes	Yes
Auto stop when in need of ice exchange	Yes	Yes
Room temperature	No	Yes
Concrete temperature, with temperature sensor specimen	No	Yes
Temperature in insulated cylinder	No	Yes
Horizontal pretension of the concrete specimen	No	Yes
Horizontal force, friction between concrete and ice	No	Yes

Table 4 - Labview control and logging capabilities

See appendix A for screenshots of NTNU Ice abrasion laboratory LabView program.

iv. Measuring of abrasion

Measuring of the abrasion can either be done mechanical or digitally with an advanced camera/laser scanner. Mechanical measuring is faster and requires less equipment and computer power. Mechanical measuring is done with a digital indicator.

ATOS 3 by GOM Optical Measuring Techniques is the name of the digital scanner. This advanced camera photographs the concrete specimen and gives you a digital picture with very accurate measurement of the abrasion. It is build up by 2 cameras and a projector in the middle. Space in between the two cameras is needed for taking pictures scans in three dimensions. In order to measure objects of different sizes the camera and projector lens can be switched out.

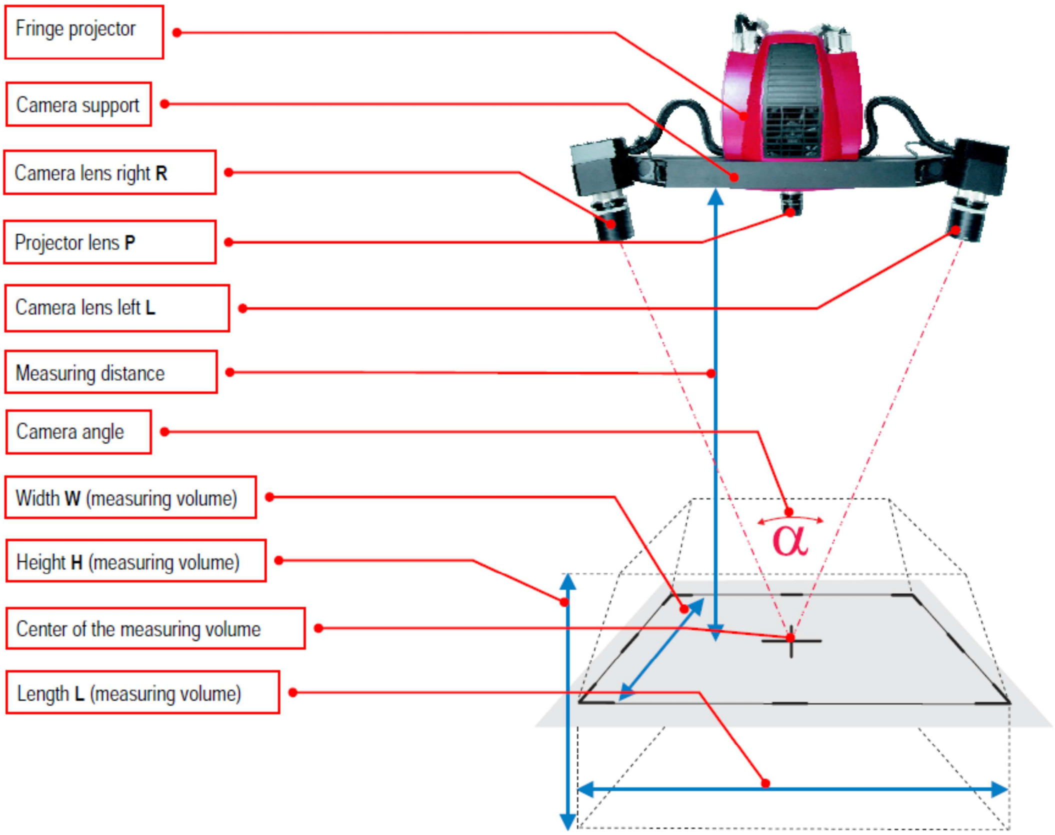


Figure 24 - ATOS Scanner standard setup with identification of components

In figure 24 you can see the standard setup of the ATOS 3 scanner. In order to get a correct scan of your object it needs to have sufficient contrast on the surface. For best results a light and dull surface with dark background is wanted. On the surface of your object it is also needed to put on reference points. The reference points are small self-adhesive or magnetic marks with a defined geometry and high contrast. Circular or square marks which are black with a white circle in the middle are used. The easiest objects to 3D digitize is objects that fits into the measuring volume. This makes the need of individual measurements smaller [24]. Even though the concrete sample fits into the ATOS measuring volume the amount of data created by the ATOS scanner is big and requires significant computing power.

Figure 25 - Concrete sample with self-adhesive circular marks

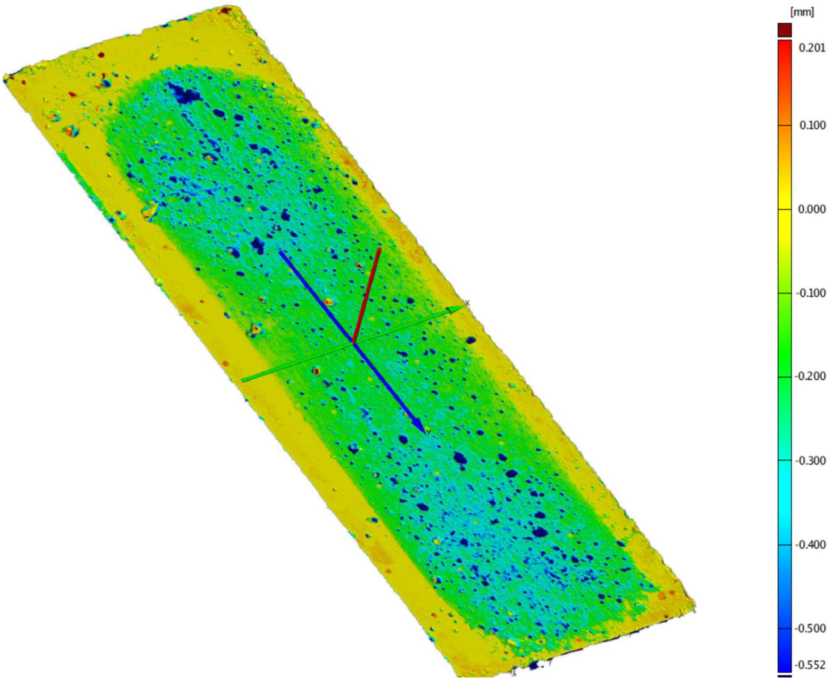


Figure 26 - Contour plot by Laser scan of concrete surface wear (Møen 2009/NTNU Ice abrasion lab)

Figure 25 shows an example scan made by Egil Møen. Standard concrete w/c = 0.60, 1 km sliding distance 1 MPa contact pressure, ice temperature -10°C. Darker color means deeper abrasion.

Mechanical abrasion measuring with a digital indicator is a fast and easy method of measuring abrasion. The concrete specimen is mounted in rig and measurements are made with a digital indicator at a predefined coordinate system, mentioned in 3.4.i. To ensure that the right points are measured the concrete specimen lies on a coordinate table. A coordinate table is a table where you can precisely move the tabletop in the plane. The digital indicator used at NTNU now the Mitutoyo Corp. 543-270B ID-C1012B. The Mitutoyo has an accuracy of 0.02 mm.

Figure 27 - Mitutoyo Corp. 543-270B Digital indicator

Figure 28- Mechanical measuring test setup

2. Test procedure

i. Preparation:

In order to start a test you have to choose type of concrete you want to test. Concrete may be casted after the right specifications or drilled out of the wanted concrete structure. The concrete needs to be in the size defined by the test rig. Length 310 mm, width 100 mm and thickness 50 mm. When casting, casting the concrete in twice the thickness then cutting the concrete specimens in half is a good alternative. Initial treatment of the concrete may be applied, such as freeze-thaw cycles or saturation and drying. After initial treatment is done pretest surface measurement has to made, either with ATOS scanner or mechanical measuring with a digital indicator. This is done to have a zero abrasion reference. The concrete specimen is now ready for testing.

The test laboratory at NTNU uses standard bore size cylindrical ice with a diameter of 74mm. This ice cylinders could be drilled out in sea ice or casted at the laboratory. To avoid massive corrosion of the lab equipment the ice used for testing is ice made from tap water at location. Mean abrasion amount on total sliding distance has been found to be almost the same as sea ice.[17] Plastic cylinders with inner diameter of 74 mm is filled up with water and put in the freezer or just in the laboratory if it is kept cool testing. As we can see from the picture, air is trapped inside the ice cylinder due to freezing from all directions at the same time. This may cause a weaker ice. Ice without this weakness could be made at an ice grow laboratory where a basin of water is frozen from top to bottom and ice samples could be drilled out of the ice sheet without this defect.

Figure 29 - Ice cylinders with and without formwork

Calibration of the sensors should be completed before testing. In the calibration tab in labview, calibration of both horizontal and vertical pressure sensors can be made. This is done by calibrating with zero load and a known load.

To make sure your test will give meaningful test data you have to decide the test settings. The different settings which is adjustable is contact pressure between ice and concrete, sliding speed, ice and lab temperature and temperature in the concrete bedding.

Contact pressure between ice and concrete is set in the main tab of labview. The value input is newton, in order to get pressure in MPa the number is divided by the area in mm^2. Ice area is 4300 mm^2. So a load of 4300 newton will give 1 MPa contact pressure. To other variables is needed to ensure correct contact pressure. Vertical engine speed determines application speed of the vertical ice load. 1350 revolutions per minute (rpm) are found to keep the vertical load stable. The down drift, the distance the vertical engines pushes the ice when pressure is below wanted, has to be determined as well. Setting this distance to high may cause a too high pressure right after being too low. A low down drift distance may cause the engine to run very often. 0.005 mm has proven to give a fairly constant pressure. Both of these variables are set in the main window of labview.

Sliding speed is set by the rpm on the horizontal engine. Labview gives you the average speed over the cycle so by testing some different speeds the right rpm can found. 565 rpm is found to give an average speed of 0.1 m/s.[25]

The concrete bedding optimal temperature should be found with a concrete specimen with temperature sensors casted inside. By testing with this concrete you can find the temperature which gives about 0 degrees at the concrete surface. If no concrete specimen with temperature sensors is availabe it is also possible to make a test run and inspect the surface of the concrete while the test is running. Start with a low temperature in the concrete bedding then increase temperature stepwise, when there is no longer an ice surface on the concrete the bedding temperature is ok.

Lab temperature is set on the cooler control panel located just outside the refrigerated room.

Wanted total sliding distance is put in “Stopp at horisontal distanse” input field in the LabView main windows.

The last step in the preparation face is to make sure logging is activated. Logging is either done cycle wise or by number of reports per second. This is adjusted in the logging tab in labview.

ii. Running the machine:

Before starting the machine the test the concrete has to be mounted on the concrete bedding and fixed with the appropriate pretension. Make sure the Julabo heater is turned on to prevent freezing of the concrete specimen. Bringing the concrete into the lab and mounting it directly on the heated copper plate prevents it from ever freezing, minimizing danger of internal frost damage .Then an ice cylinder needs to be placed in the ice compartment. When the ice is in place the bedding is placed moved under the ice compartment. This is done manually, a wheel on the side of the machine moves the bedding horizontally.

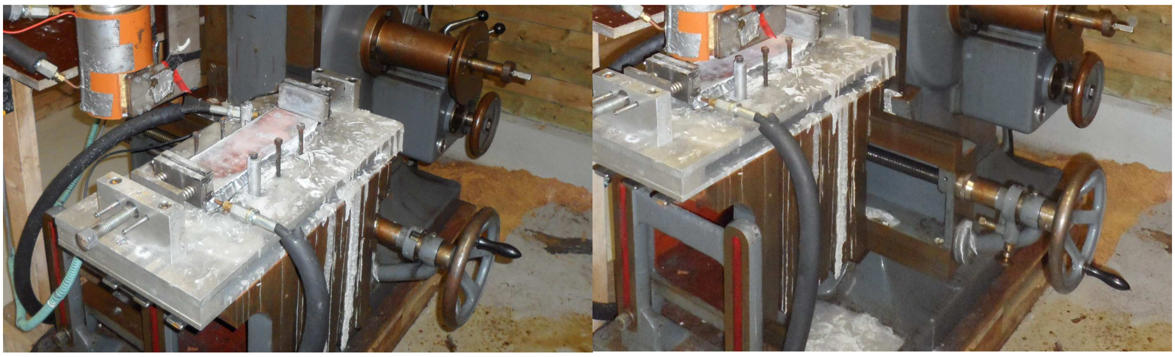


Figure 30 - Concrete bedding in both positions, manually moved by wheel with handle in bottom right corner

Now testing is ready to start. It is important to start the horizontal movement before applying vertical pressure. If vertical pressure is applied first the ice may fasten to the concrete and this may cause unwanted damage to the concrete. When the horizontal engine is started by pushing the Run/Stop button, the vertical pressure may be applied. This is done by pushing the v. last automatikk ned på (in English: vertical load automatic down on) button. Immediately as this button is turned the logging begins. This means the test has started.

The machine will run by itself and logging in wanted pace until either the ice runs out, or wanted horizontal distance is acquired. When ice runs out or wanted distance is acquired an alarm starts in labview. Labview will make continuous beeping for about 5 seconds and set the machine in inspection needed mode. This inspection needed mode raises the vertical engine to top position turning of ice pressure. The horizontal engine is set to 400 rpm, this is done in order to ensure that the remaining ice not will fasten to the concrete.


Figure 31 - Valves behind Julabo heater

When the machine runs out of ice a new ice cylinder will need to be installed to continue testing. To change ice, stop the horizontal engine by pushing Run/Stop button. Then move the concrete bedding to the side with the wheel. Moving the concrete bedding to side should be done within minutes after stopping the horizontal engine, preferably as soon as possible. To remove remaining ice in the ice compartment the heat flow to the ice compartment needs to be switched on. This is done by opening the valves behind the Julabo. When remaining ice is removed, turn off the heating of the ice compartment. If this is not done the ice will melt extremely fast during testing. Then insert new ice cylinder and move concrete bedding back underneath ice compartment.

The test can now continue. Remember to adjust horizontal rpm back to wanted speed, as the inspection needed mode has set the speed to 400 rpm. Push the Run/Stop button then push the v. last automatikk ned på (in English: vertical load automatic down on). The test is now running and logging again.

Repeated changes of ice will be necessary. Ice wear will vary. Pressure, temperature, speed and surface may affect wear. Several ice changes per effective kilometer have to be expected.

iii. After testing:

When wanted sliding distance is acquired the alarm will go off. Then it is time to remove the concrete from the machine. Stop the horizontal engine by pushing the Run/Stop button. Then move the concrete bedding to the side release the pretension and lift the concrete out. When the concrete specimen is removed from the bedding it is ready for a new surface measurement. By comparing the pretest measurement with the new measurement we can obtain abrasion data.

Log files from labview should be obtained and stored in wanted archive. They are located at D:\!!! on lab computer. These log files contains all test data recorded by labview.

iv. Test procedure quick guide step by step:

Preparation

1. Choosing type of concrete to test.
2. Casting the concrete.
3. Initial treatment of the concrete, for example freeze/thaw , saturation and drying
4. Pretest surface measurement
5. Make ice
6. Decide test settings, ice/concrete pressure, sliding speed and distance, temperature in bedding to ensure ice free surface and pretension of concrete
7. Make sure calibration of machine is ok (calibration windows in LabView)
8. Make sure logging is activated (log windows in LabView)

Running the machine

1. Mount the concrete specimen in the bedding with correct pretension.
2. Insert ice.
3. Make sure bedding is located in start position, directly underneath ice cylinder.
4. Hit Run/Stop button (main window LabView)
5. Apply vertical loading (main window LabView)

The machine will stop when ice is abraded away or wanted sliding distance is obtained. If wanted distance is not obtained change the ice and restart the machine.

Post testing

1. Remove concrete specimen from the bedding.
2. Measure abrasion with desired method.
3. Obtain log file from LabView and store in archive.

5. Testing

In this test 4 concrete samples has been tested for ice abrasion. Two double sized concrete samples with size 31x10x10 cm were cut in half to create 2 + 2 equal samples. From the first concrete specimen we have sample A1 and A2 from the second B1 and B2. Both samples were standard w/c=0.6 concrete with air, made at the NTNU concrete laboratory in 2008. Storage has differed through the years. The last years they have stored partly covered in plastic in room temperature at the laboratory.

The goal for this test was to find out if drying and resaturation of concrete would increase the abrasion rate of the concrete. All four samples were saturated. Sample A2 and B2 was then dried for 1 week at 50 degrees and then resaturated. Table below shows weight development throughout saturation, drying and resaturation.

Weight development concrete specimens [g]	A1	A2	B1	B2
13.04.2012	3480	3595,7	3648,2	3461,2
17.04.2012	3511,9	3614,9	3692,5	3489,4
21.04.2012	3516,2	3616,2	3695,6	3491,2
25.04.2012	3524	3619,4	3703,6	3498
23.05.2012	3524	3619	3703	3498
		Drying		Drying
01.06.2012		3539,6		3411
04.06.2012		3615,9		3491,7
08.06.2012		3618,8		3497,6

Table 5 - Weight development during saturation of concrete samples

All test where performed according to chapter 4.2 test procedure.

1. Abrasion results

i. Concrete sample A1

Test parameters	
Concrete type	w/c = 0,6 std. Concrete with air
Initial concrete treatment	Saturated
Contact pressure ice/concrete	1 Mpa
Ice temperature/Ambient temperature Tice	-10 °C
Velocity range over one cycle	0 – 0,2 m/s
Average ice sliding velocity	0,1 m/s
Total ice sliding distance	1350m
Total, effective ice exposure at a point on the concrete surface	500 m
Total test duration each specimen	about 4 hours

Table 6 - Test parameters concrete sample A1

Comments:

Originally 1000 m effective sliding distance was wanted, and a mid-test measure of the abrasion after 500m. Unfortunately the concrete specimen could not handle the forces applied by the ice abrasion machine and cracked into 3 pieces during the test. The cracking of the concrete happened after the first ice change, which in meters will be around 500 meters of sliding. After abrasion measurement at 500 effective meters, the condition of the concrete specimen was not good enough to continue testing. Results after 500 effective meters are given below.

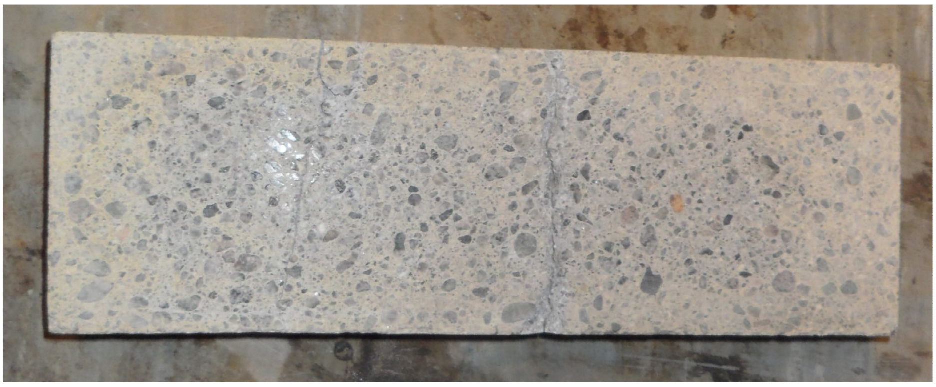


Figure 32 - Picture of concrete sample A1 after abrasion testing

Results summary		Average Abrasion 0 - 500 m Total [mm]	Average Abrasion 0 - 500 m [mm/km]
Specimen	**A1**		
Pressure	**1,0 Mpa**		
Temperature	**-10 °C**		
Section	y = 0	-0,195	-0,390
Section	y = 20	-	-
Section	y = 40	-0,004	-0,008
Section	y = 60	0,006	0,012
Section	y = 80	0,017	0,034
Section	y = 100	-0,001	-0,002
Section	y = -20	-0,080	-0,160
Section	y = -40	-0,064	-0,128
Section	y = -60	-0,028	-0,057
Section	y = -80	-0,206	-0,412
Section	y = -100	-0,148	-0,296

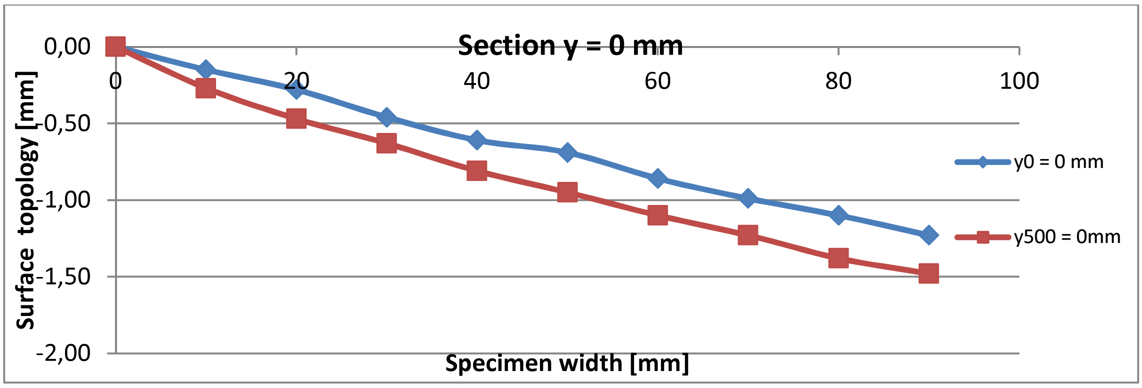
Table 7 - Results summary A1

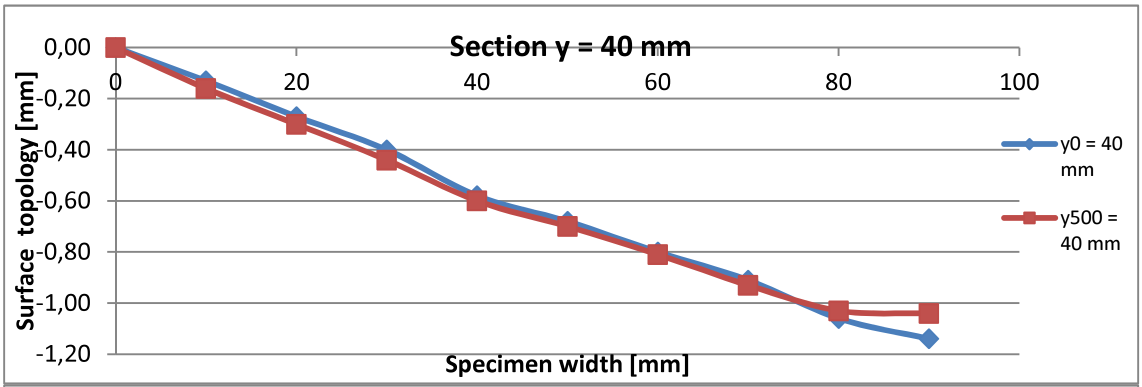
Ice abrasion depth all points
Specimen A1
Total distance 500 meter

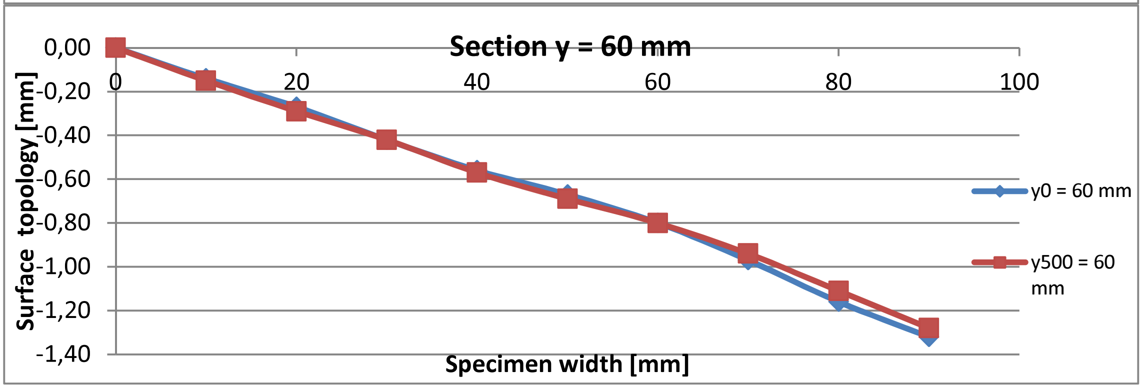
	x										**Avarage each section [mm]**
y	0	10	20	30	40	50	60	70	80	90	
100	0	-0,01	-0,01	-0,01	-0,05	-0,05	0	0,02	0,07	0,03	-0,001
80	0	-0,01	0	-0,01	-0,03	0	0	0,03	0,11	0,08	0,017
60	0	-0,01	-0,02	0	-0,01	-0,02	0	0,03	0,05	0,04	0,006
40	0	-0,03	-0,03	-0,04	-0,02	-0,02	-0,01	-0,02	0,03	0,1	-0,004
20	-	-	-	-	-	-	-	-	-	-	-
0	0	-0,12	-0,19	-0,17	-0,2	-0,26	-0,24	-0,24	-0,28	-0,25	-0,195
-20	0	-0,02	-0,05	-0,08	-0,08	-0,09	-0,13	-0,12	-0,12	-0,11	-0,080
-40	0	-0,02	-0,04	-0,07	-0,06	-0,09	-0,09	-0,08	-0,09	-0,1	-0,064
-60	0	0	-0,06	-0,03	-0,13	0,05	0,15	-	-	-	-0,003
-80	0	-0,05	-0,12	-0,17	-0,21	-0,25	-0,28	-0,34	-0,29	-0,35	-0,206
-100	0	-0,03	-0,07	-0,09	-0,17	-0,21	-0,21	-0,22	-0,24	-0,24	-0,148
Avarage all sections											-0,062

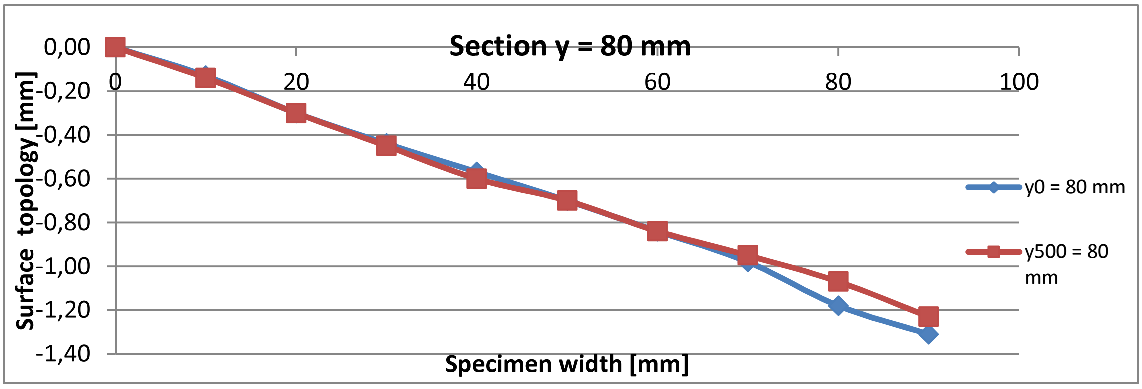
Table 8 - Abrasion results all measured points A1

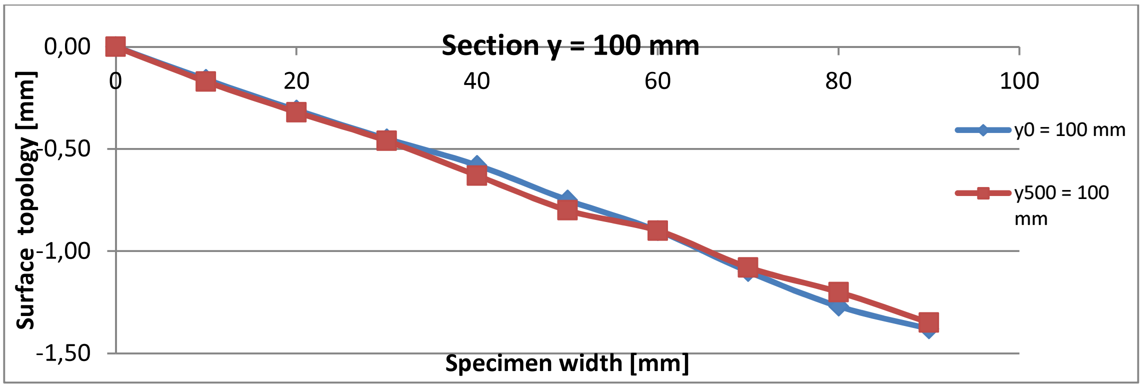
Section y=20 and last 3 points at y=-60 has no measurement due to cracking in concrete specimen.

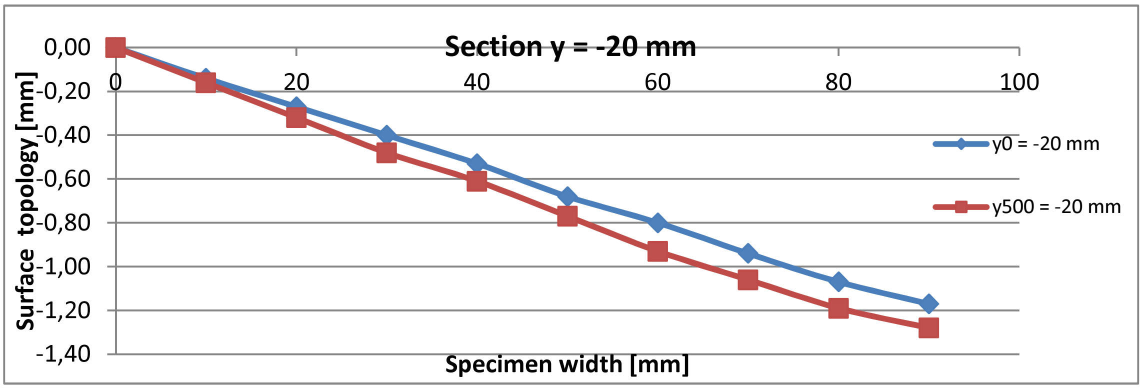

Section y = 0 mm
Surface topology [mm]
0,00
-0,50
-1,00
-1,50
-2,00
0
20
40
60
80
100
Specimen width [mm]
y0 = 0 mm
y500 = 0mm


Section y = 40 mm
Surface topology [mm]
0,00
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
0
20
40
60
80
100
Specimen width [mm]
y0 = 40 mm
y500 = 40 mm


Section y = 60 mm
Surface topology [mm]
0,00
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
-1,40
0
20
40
60
80
100
Specimen width [mm]
y0 = 60 mm
y500 = 60 mm


Section y = 80 mm
Surface topology [mm]
0,00
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
-1,40
0
20
40
60
80
100
Specimen width [mm]
y0 = 80 mm
y500 = 80 mm


Section y = 100 mm
Surface topology [mm]
0,00
-0,50
-1,00
-1,50
0
20
40
60
80
100
Specimen width [mm]
y0 = 100 mm
y500 = 100 mm


Section y = -20 mm
Surface topology [mm]
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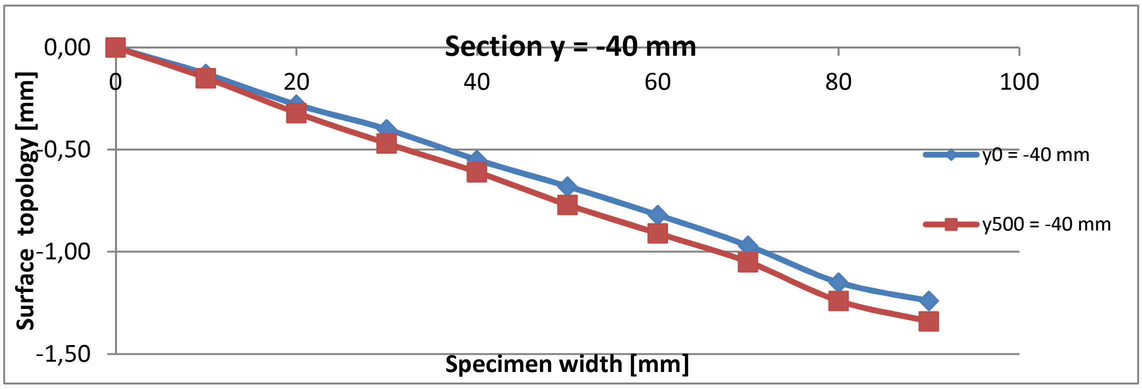
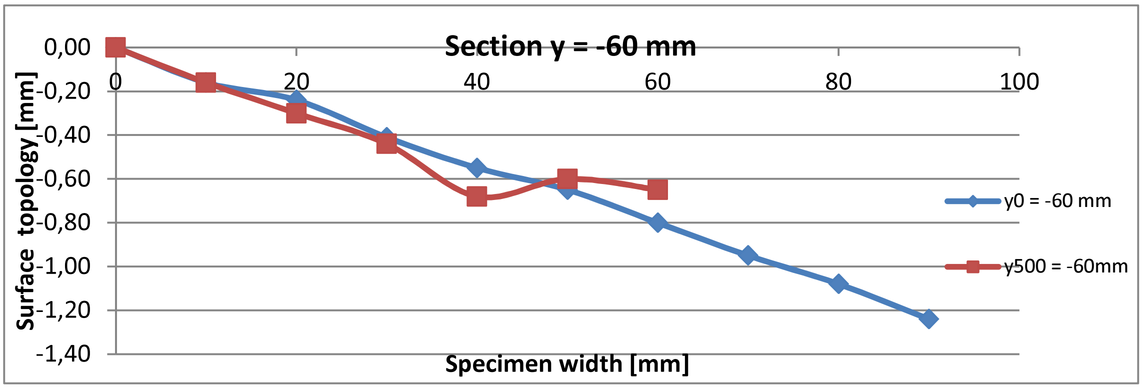
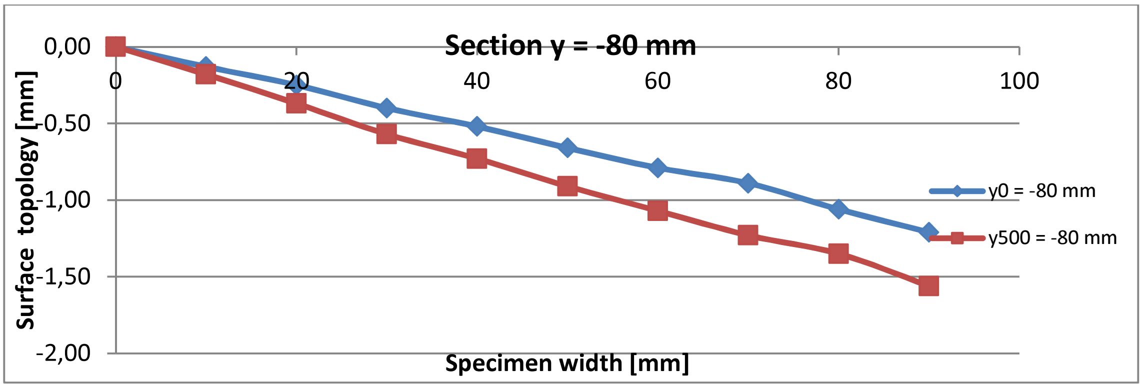
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
-1,40
0
20
40
60
80
100
Specimen width [mm]
y0 = -20 mm
y500 = -20 mm


Section y = -40 mm
Surface topology [mm]
0,00
-0,50
-1,00
-1,50
0
20
40
60
80
100
Specimen width [mm]
y0 = -40 mm
y500 = -40 mm


Section y = -60 mm
Surface topology [mm]
0,00
-0,20
-0,40
-0,60
-0,80
-1,00
-1,20
-1,40
0
20
40
60
80
100
Specimen width [mm]
y0 = -60 mm
y500 = -60mm



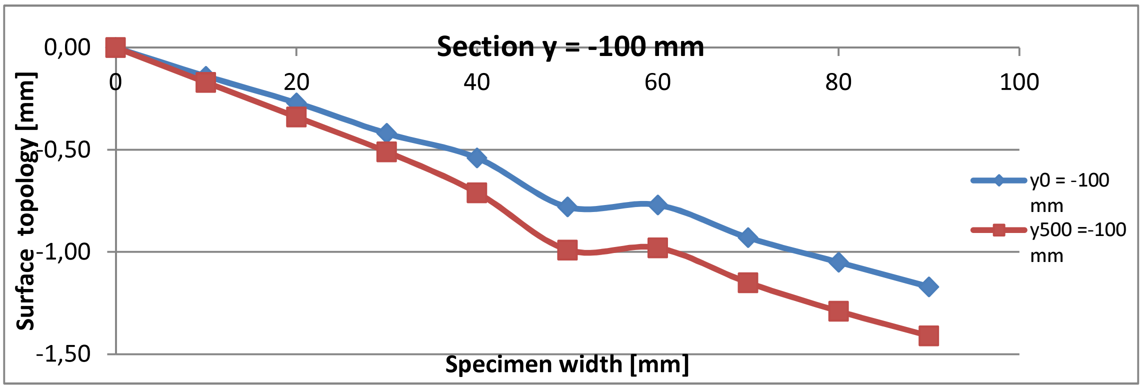


Figure 33 - Surface topography of all sections A1

Figure 33 shows surface topography of all sections before and after 500 testing. Distance between the blue and red line indicates the abrasion.

ii. Concrete sample B1

Test parameters	
Concrete type	w/c = 0,6 std. Concrete with air
Initial concrete treatment	Saturated
Contact pressure ice/concrete	1 Mpa
Ice temperature/Ambient temperature Tice	-10 °C
Velocity range over one cycle	
Average ice sliding velocity	0,1 m/s
Total ice sliding distance	1350m
Total, effective ice exposure at a point on the concrete surface	500 m
Total test duration each specimen	about 4 hours

Table 9 - Test parameters concrete sample B1

Comments:

Originally 1000 m effective sliding distance was wanted, and a mid-test measure of the abrasion after 500m. Unfortunately the concrete specimen could not handle the forces applied by the ice abrasion machine and cracked into 2 pieces during the test. The cracking of the concrete happened after the second ice change, which in meters will be around 800 meters of sliding. After abrasion measurement at 500 effective meters, the condition of the concrete specimen was not good enough to continue testing. Results after 500 effective meters are given below.

Figure 34 - Picture of concrete sample B1 after abrasion testing

Results summary		Average Abrasion 0 - 500 m Total [mm]	Average Abrasion 0 - 500 m [mm/km]
Specimen	**B1**		
Pressure	**1,0 Mpa**		
Temperature	**-10 °C**		
Section	y = 0	-0,538	-1,076
Section	y = 20	-0,544	-1,088
Section	y = 40	-0,515	-1,030
Section	y = 60	-0,519	-1,038
Section	y = 80	-0,474	-0,948
Section	y = 100	-0,528	-1,056
Section	y = -20	-0,730	-1,460
Section	y = -40	-0,655	-1,310
Section	y = -60	-0,382	-0,764
Section	y = -80	-0,605	-1,210
Section	y = -100	-0,575	-1,150

Table 10 - Results summary B1

Ice abrasion depth all points **Specimen B1** **Total distance 500 meter**											
	x										**Avarage each section [mm]**
y	0	10	20	30	40	50	60	70	80	90	
100	0	-0,11	-0,22	-0,35	-0,49	-0,61	-0,71	-0,82	-0,93	-1,04	-0,528
80	0	-0,14	-0,25	-0,4	-0,51	0,208	-0,73	-0,9	-0,95	-1,07	-0,474
60	0	-0,1	-0,24	-0,33	-0,46	-0,57	-0,71	-0,79	-0,95	-1,04	-0,519
40	0	0,03	-0,23	-0,36	-0,49	-0,57	-0,71	-0,86	-0,92	-1,04	-0,515
20	0	-0,14	-0,25	-0,38	-0,5	-0,61	-0,71	-0,84	-0,95	-1,06	-0,544
0	0	-0,16	-0,23	-0,36	-0,48	-0,6	-0,71	-0,84	-0,95	-1,05	-0,538
-20	0	-0,35	-0,31	-0,46	-0,64	-0,8	-0,95	-1,11	-1,3	-1,38	-0,730
-40	0	-0,12	-0,28	-0,45	-0,61	-0,76	-0,92	-1,03	-1,15	-1,23	-0,655
-60	0	0,07	0,06	-0,11	-0,28	-0,45	-0,58	-0,74	-0,84	-0,95	-0,382
-80	0	-0,15	-0,29	-0,42	-0,53	-0,69	-0,8	-0,94	-1,06	-1,17	-0,605
-100	0	-0,16	-0,29	-0,46	-0,59	-0,71	-0,8	-0,98	-0,57	-1,19	-0,575
Avarage all sections											-0,551

Table 11 - Abrasion results all measured points B1

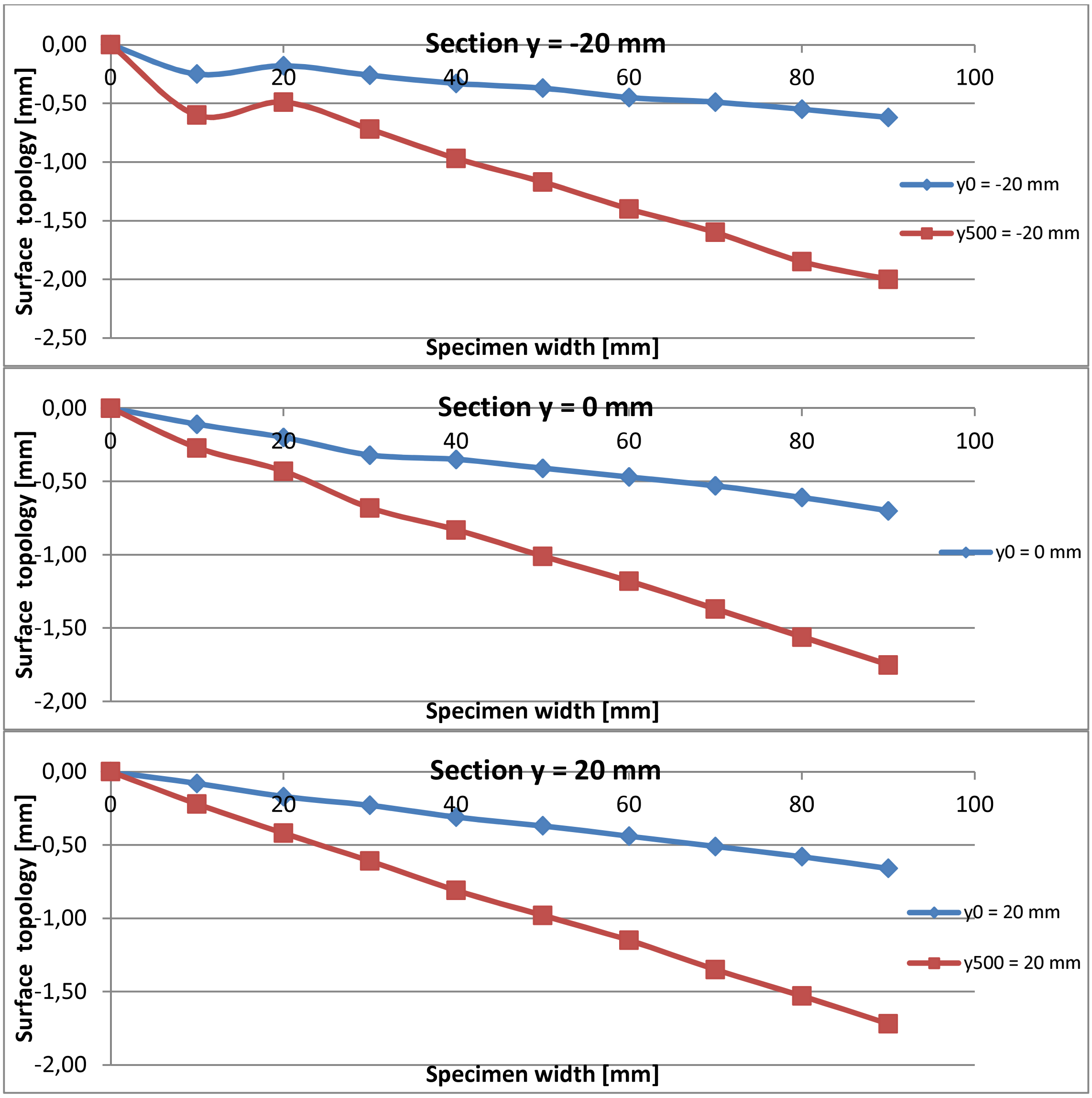


Figure 35 - Surface topography of selected sections B1

Figure 35 shows surface topology for the 3 most central sections, the other sections look about the same and are therefore not included. They are all available in measurement excel document. Distance between the blue and red line indicates the abrasion.

iii. Concrete sample A2

Test parameters	
Concrete type	w/c = 0,6 std. Concrete with air
Initial concrete treatment	Saturated, dried, resaturated
Contact pressure ice/concrete	1 Mpa
Ice temperature/Ambient temperature Tice	-10 °C
Velocity range over one cycle	
Average ice sliding velocity	0,1 m/s
Total ice sliding distance	1350m
Total, effective ice exposure at a point on the concrete surface	500 m
Total test duration each specimen	about 4 hours

Table 12 - Test parameters concrete sample A2

Comments:

Originally 1000 m effective sliding distance was wanted, and a mid-test measure of the abrasion after 500m. Unfortunately the concrete specimen could not handle the forces applied by the ice abrasion machine and cracked into 2 pieces during the test. The cracking of the concrete happened fast during the first ice block, in meters around 100 meters of sliding. After abrasion measurement at 500 effective meters, the condition of the concrete specimen was not good enough to continue testing. Results after 500 effective meters are given below.

Figure 36 - Picture of concrete sample A2 after abrasion testing

Results summary		Average Abrasion 0 - 500 m Total [mm]	Average Abrasion 0 - 500 m [mm/km]
Specimen	**A2**		
Pressure	**1,0 Mpa**		
Temperature	**-10 °C**		
Section	y = 0	-0,007	-0,014
Section	y = 20	-0,032	-0,064
Section	y = 40	-0,038	-0,076
Section	y = 60	0,000	0,000
Section	y = 80	-0,045	-0,090
Section	y = 100	-0,150	-0,300
Section	y = -20	-0,006	-0,012
Section	y = -40	0,008	0,016
Section	y = -60	0,023	0,046
Section	y = -80	-0,004	-0,008
Section	y = -100	0,000	0,000

Table 13 - Results summary A2

Ice abrasion depth all points
Specimen A2
Total distance 500 meter

	x										**Avarage**
y	0	10	20	30	40	50	60	70	80	90	**each section**
100	0	-0,13	-0,19	-0,15	-0,15	-0,18	-0,16	-0,16	-0,2	-0,18	-0,150
80	0	-0,06	-0,03	-0,03	-0,1	-0,05	-	-	-	-	-0,045
60	-	-	-	-	-	-	-	-	-	-	-
40	0	0	-0,03	-0,03	-0,07	-0,05	-0,03	-0,06	-0,06	-0,05	-0,038
20	0	-0,03	-0,05	-0,04	-0,04	-0,04	-0,05	-0,03	-0,02	-0,02	-0,032
0	0	0	-0,01	-0,02	0,01	-0,01	-0,01	-0,01	-0,02	0	-0,007
-20	0	-0,02	-0,03	-0,02	-0,03	0	-0,01	0	0	0,05	-0,006
-40	0	0,01	-0,01	-0,02	0,01	0,03	0	0,02	0,03	0,01	0,008
-60	0	0,02	0,01	0,01	0,01	0,01	0,02	0,03	0,05	0,07	0,023
-80	0	0	-0,01	-0,01	-0,02	-0,02	-0,01	0	0,01	0,02	-0,004
-100	0	-0,01	-0,01	-0,01	-0,01	-0,01	-0,02	0	0,04	0,03	0,000
Avarage all sections											-0,025

Table 14 - Abrasion results all measured points A2

Section y=60 and last 4 points at y=80 has no measurement due to cracking in concrete specimen.

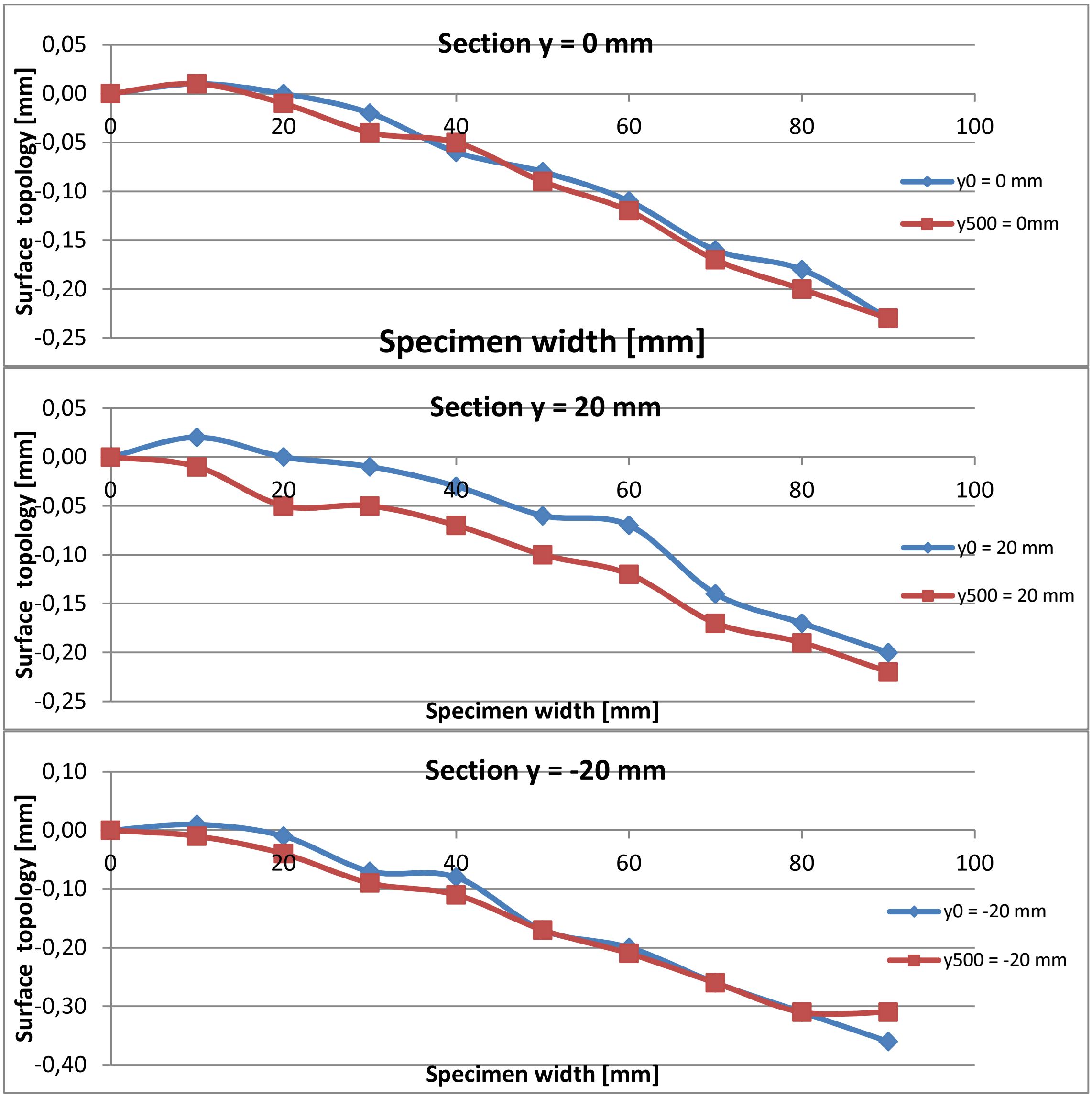


Figure 37 - Surface topography of selected sections A2

Again surface topology for the 3 most central sections is given, the other sections look about the same and are therefore not included. They are all available in measurement excel document. Distance between the blue and red line indicates the abrasion.

iv. Concrete sample B2

Test parameters	
Concrete type	w/c = 0,6 std. Concrete with air
Initial concrete treatment	Saturated, dried, resaturated
Contact pressure ice/concrete	1 Mpa
Ice temperature/Ambient temperature Tice	-10 °C
Velocity range over one cycle	
Average ice sliding velocity	0,1 m/s
Total ice sliding distance	1350m
Total, effective ice exposure at a point on the concrete surface	500 m
Total test duration each specimen	about 4 hours

Table 15 - Test parameters concrete sample B2

Comments:

Originally 1000 m effective sliding distance was wanted, and a mid-test measure of the abrasion after 500m. Unfortunately the concrete specimen could not handle the forces applied by the ice abrasion machine and cracked into 2 pieces during the test. The cracking of the concrete happened very fast during the first ice block, in meters around 25 meters of sliding. After abrasion measurement at 500 effective meters, the condition of the concrete specimen was not good enough to continue testing. Results after 500 effective meters are given below.

Figure 38 - Picture of concrete sample B2 after abrasion testing

Results summary		Average Abrasion 0 - 500 m Total [mm]	Average Abrasion 0 - 500 m [mm/km]
Specimen	**B2**		
Pressure	**1,0 Mpa**		
Temperature	**-10 °C**		
Section	y = 0	-0,036	-0,072
Section	y = 20	-0,103	-0,206
Section	y = 40	-0,063	-0,126
Section	y = 60	-0,066	-0,132
Section	y = 80	-0,040	-0,080
Section	y = 100	-0,032	-0,064
Section	y = -20	-0,046	-0,092
Section	y = -40	0,000	0,000
Section	y = -60	0,000	0,000
Section	y = -80	0,022	0,044
Section	y = -100	-0,041	-0,082

Table 16 - Results summary B2

Ice abrasion depth all points **Specimen B2** **Total distance 500 meter**											
	x										**Avarage each section**
y	0	10	20	30	40	50	60	70	80	90	
100	0	-0,01	-0,02	-0,04	-0,03	-0,03	-0,04	-0,05	-0,05	-0,05	-0,032
80	0	0	-0,04	-0,04	-0,07	-0,04	-0,03	-0,07	-0,06	-0,05	-0,040
60	0	-0,01	-0,04	-0,03	-0,09	-0,15	-0,12	-0,07	-0,09	-0,06	-0,066
40	0	-0,02	-0,04	-0,05	-0,11	-0,11	-0,08	-0,08	-0,08	-0,06	-0,063
20	0	-0,07	-0,09	-0,1	-0,18	-0,11	-0,12	-0,12	-0,12	-0,12	-0,103
0	0	-0,01	-0,02	-0,05	-0,02	-0,05	-0,05	-0,06	-0,05	-0,05	-0,036
-20	0	0	-0,03	-0,06	-0,08	-0,07	-0,04	-0,08	-0,07	-0,03	-0,046
-40	-	-	-	-	-	-	-	-	-	-	-
-60	-	-	-	-	-	-	-	-	-	-	-
-80	0	0,01	-0,02	0	0,38	-0,03	-0,03	-0,03	-0,05	-0,01	0,022
-100	0	-0,01	-0,05	-0,05	-0,09	-0,05	-0,03	-0,04	-0,06	-0,03	-0,041
Avarage all sections											-0,045

Table 17 - Abrasion results all measured points B2

Section y=-40 and points at y=-60 has no measurement due to cracking of concrete specimen.

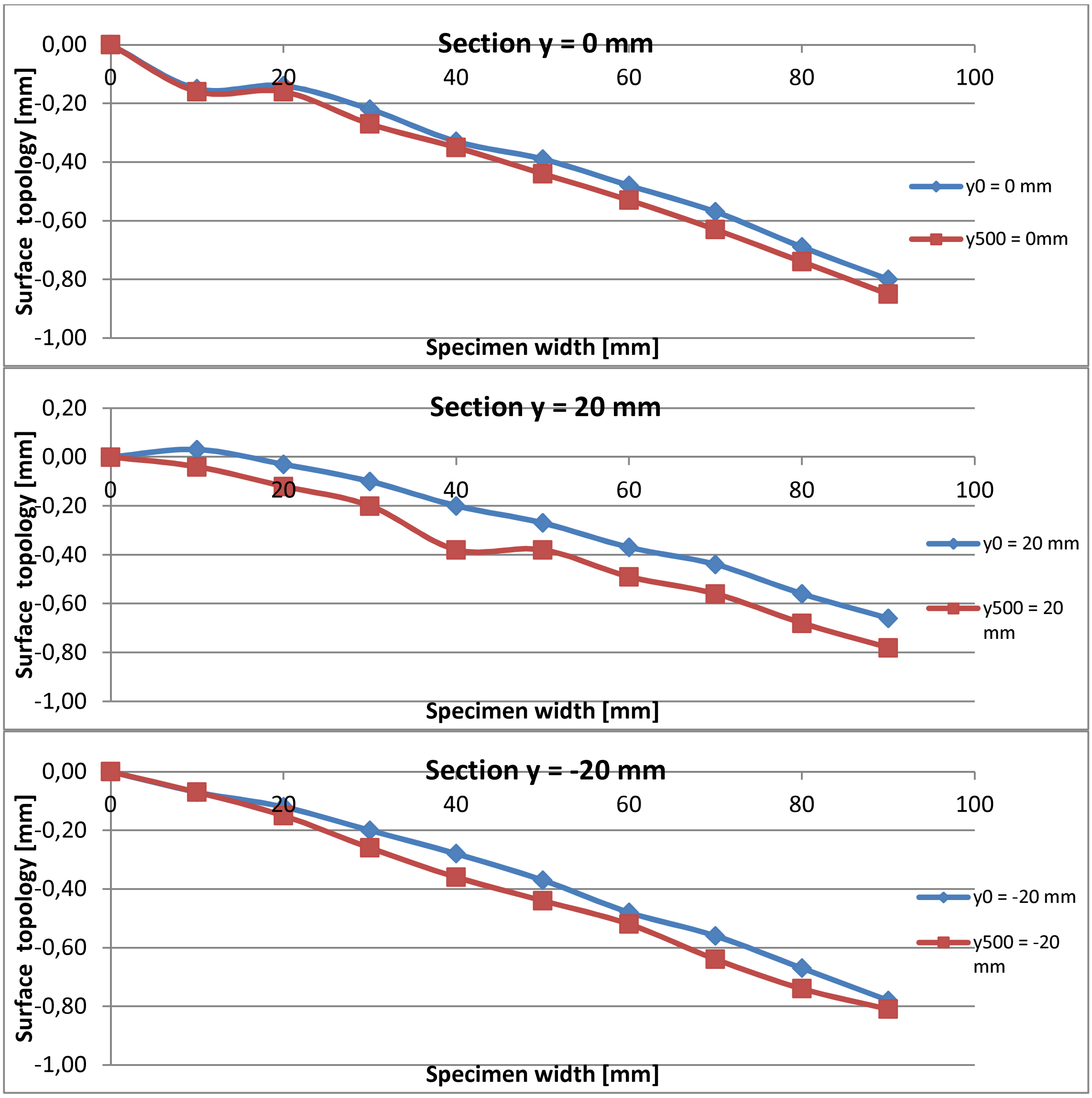


Figure 39- Surface topography of selected sections B2

Again surface topology for the 3 most central sections is given, the other sections look about the same and are therefore not included. They are all available in measurement excel document. Distance between the blue and red line indicates the abrasion.

v. Variations of test parameters during testing

During the test, test parameters such at pressure temperature and speed will vary. Below the variations during testing of concrete sample A2 is given. Similar variations occurred with the other 3 samples and only data for one test is posted in this thesis.

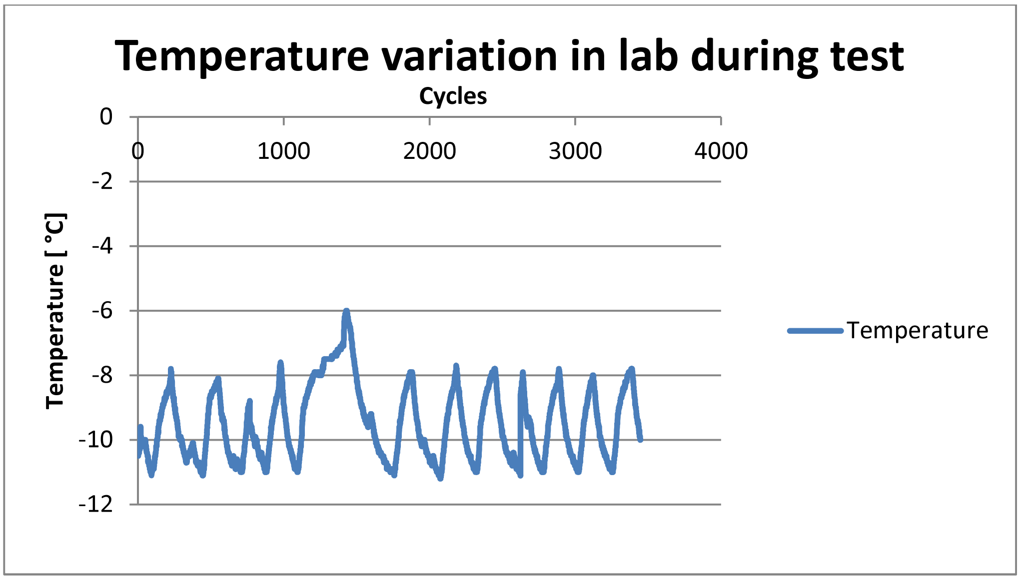


Figure 40 - Temperature variation in lab during testing

The temperature variation during testing is present due to the tolerance span of the temperature control unit. It calibrated to hold the room between -8°C and -11°C. At around 1500 cycles we see a spike in the temperature, this is probably caused by the door of the lab being opened just before the temperature reached -8°C.

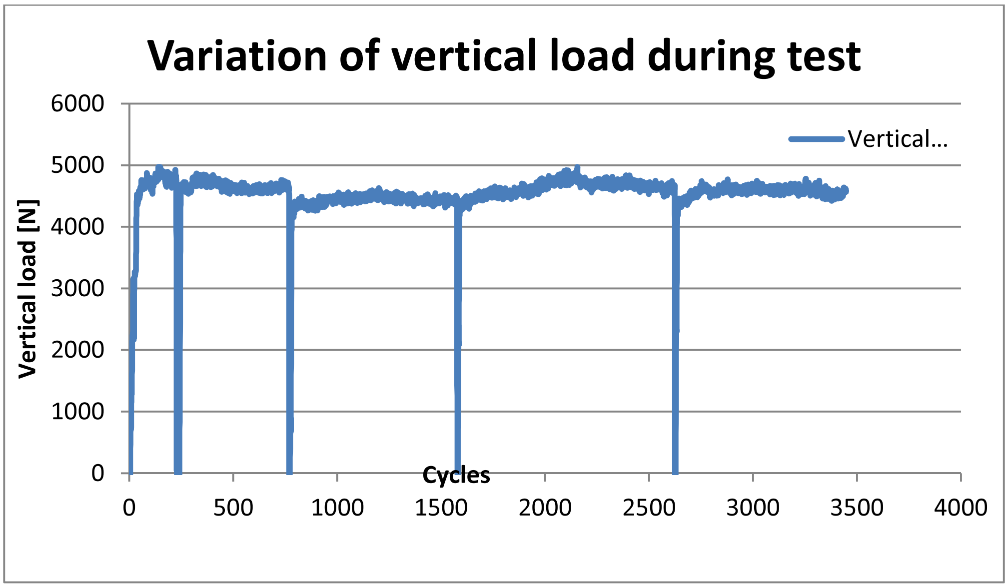


Figure 41- Variation of vertical load during testing

The variation in vertical pressure is present because the vertical engine is calibrated to apply more pressure if the it to low. When pressure is applied the engine moves pushes the ice cylinder 0,005 mm down, causing the pressure to increase. The spike in the pressure occurs when the ice is changed. The pressure is 0 when apply vertical pressure button is pushed and logging start, it then takes a few cycles to achieve wanted pressure. From the graph we can see that average load is about 4300 MPa, which is 1Mpa of contact pressure.

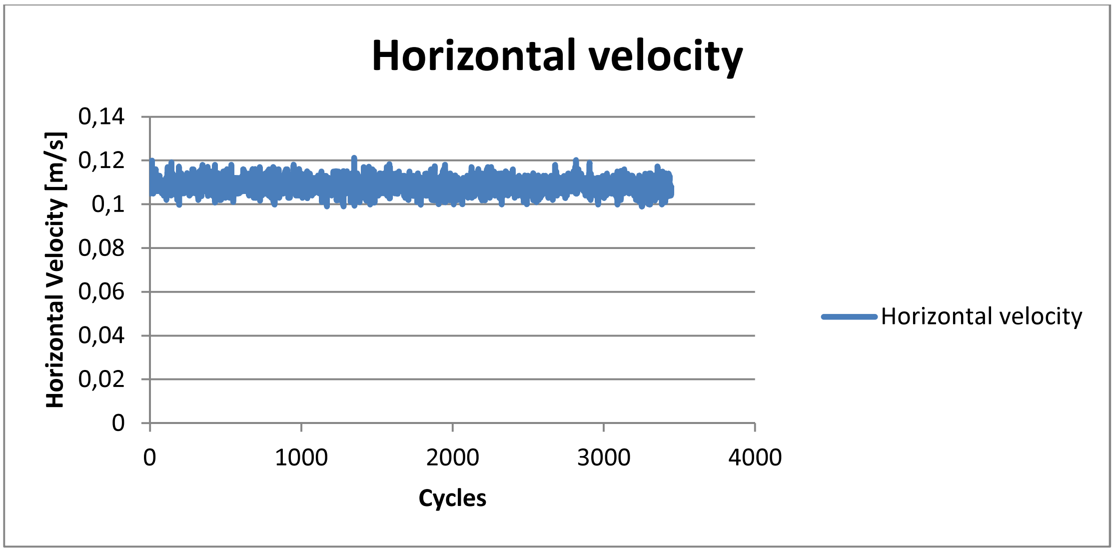


Figure 42 - Variation of horizontal velocity

Horizontal velocity is also varying over the cycles. As we can see from the graph average velocity is just over 0.1 m/s. This would imply that the previous assumption that 565 rpm on the horizontal engine is slightly too fast. All tests are run with the same speed, so comparison of the results will not suffer from slightly higher speeds.

2. Comparison, evaluation and discussions of results

A higher abrasion rate for sample A2 and B2 where expected due to their initial treatment.

It is reason to believe that cracking of the concrete samples has disturbed the test results. A cracked concrete may cause the concrete to rest on the coordinate table a different way, this will have a big impact when measuring small abrasions.

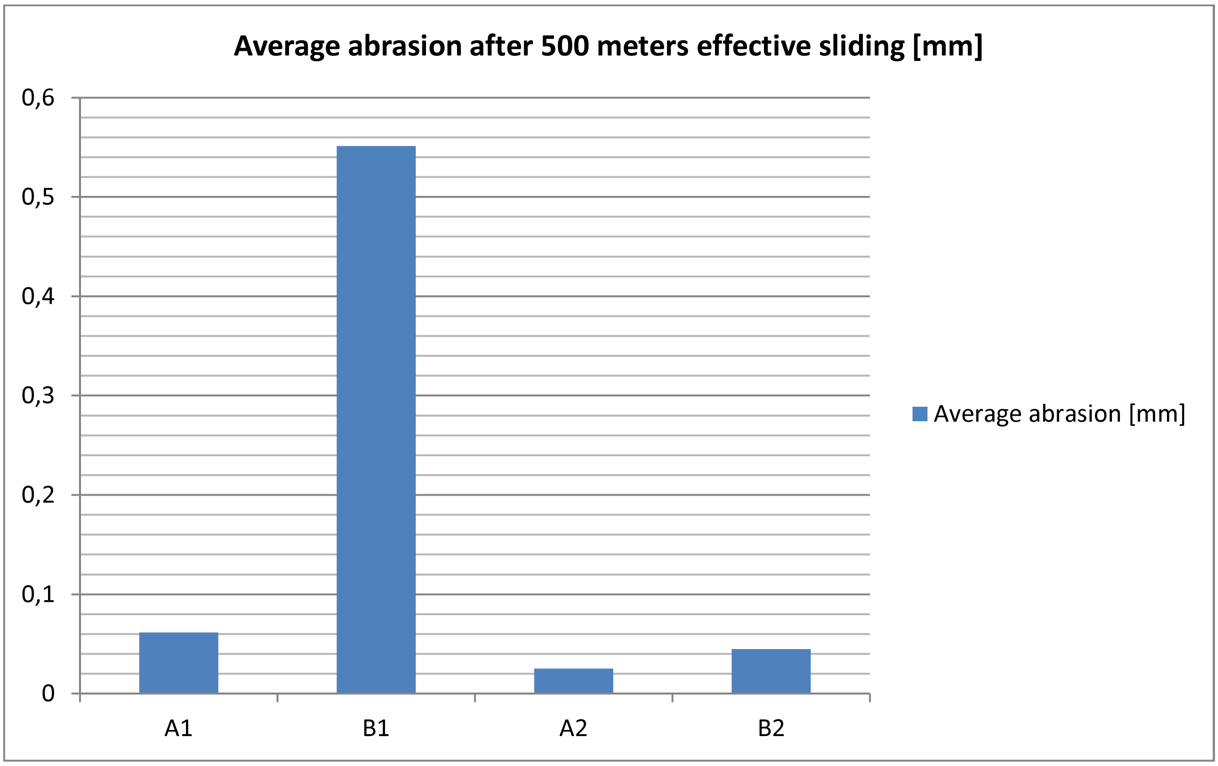


Figure 43- Average abrasion after 500m all samples

The figure above shows the average abrasion of the 4 different test samples. As we can see the results vary a lot. Small abrasion depths where expected around the depth of 0,1mm[26]. The result for concrete B1 is clearly totally corrupted by the cracking of the concrete. Results for the other concretes are in the right magnitude, but the variation here is also high.

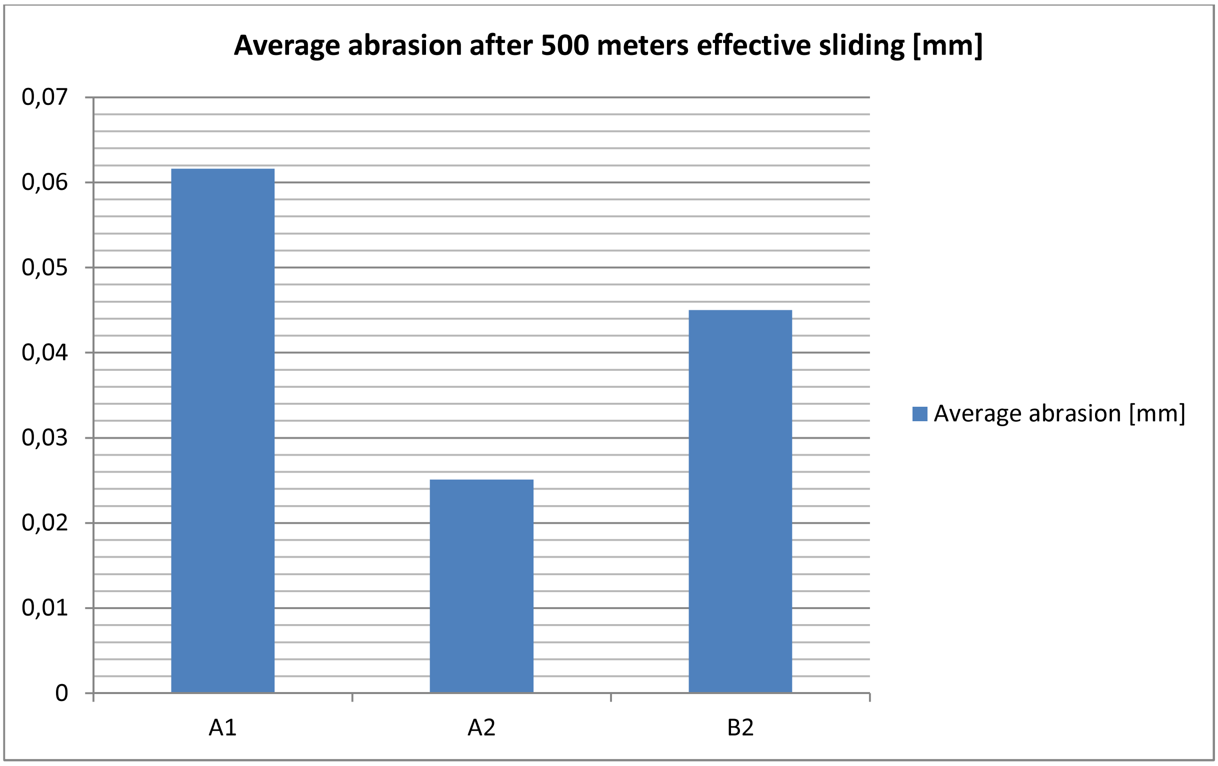


Figure 44 - Average abrasion after 500m sample A1, A2 and B2

Abrasion rates for sample A1, A2 and B2. B1 is removed to see the variation of the other 3 samples. The abrasion rates for these 3 samples are having the expected magnitude. Yet no conclusion can be made out of these results. The cracking of the concrete has caused these results to be none trustworthy.

By comparing when the concrete samples cracked up during the test some conclusion may be made.

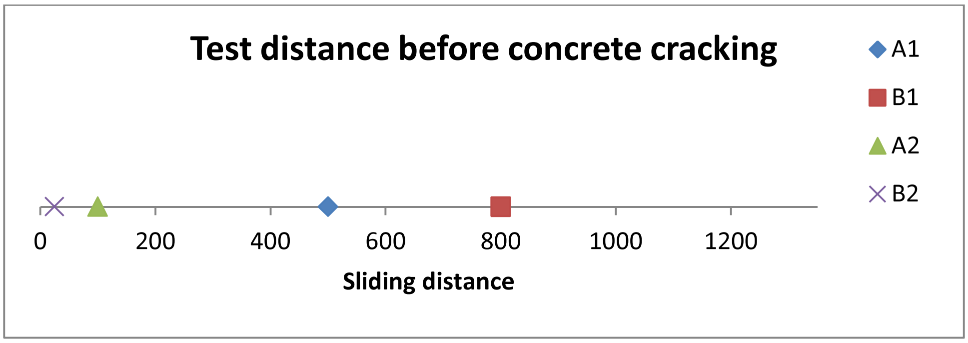


Figure 45 - Test distance before cracking of concrete

Figure 45 shows that the two concretes that was dried out and resaturated cracked at an earlier stage. This may induce that they have become weaker after this treatment.

It is a possible theory that all 4 concrete samples have been weakened by the storage at NTNU laboratory making them too weak to withstand the forces of the ice abrasion test apparatus.

All the concrete samples cracked at the same point, sample A1 cracked in two places one at the middle and one in the common point. Figure 47 shows the common crack point. At this point the ice cylinder halts and is pushed back in the other direction. At the opposite turning point when the machine pulls back no cracks occur. Either one or more of the different components underneath the concrete specimen tend to be compressed due to the pressure. One or more of these parts, concrete bedding, bearings or pressure sensors does not withstand the vertical load satisfactory. At both ends the concrete sample is pushed down. Even though this displacement is very small, it creates a none flat surface. Figure 46 shows a principle sketch on how this angle is created. Grey concrete lies on copper bedding which is placed on top on bearings (not present on sketch) with black load sensors underneath. The ice cylinder, blue in this sketch, pushes the concrete down. This small angle causes high levels of stress at the endpoints. In addition to the larger rest friction the ice cylinder now also faces an incline. Experience from these tests shows that the strain is highest at the turn point where the ice cylinder is pushed back.

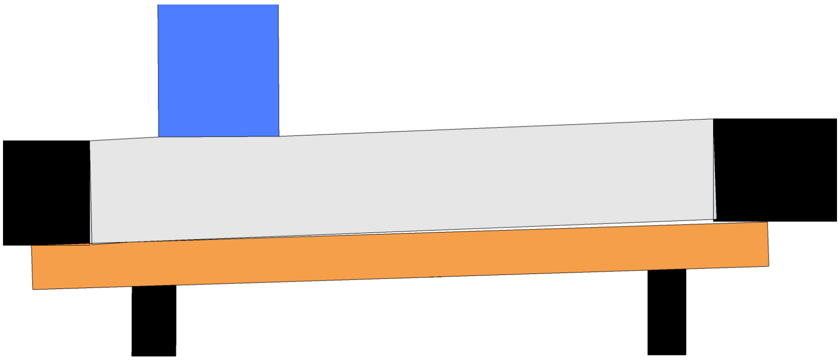


Figure 46 - Principle sketch displacement of concrete during test

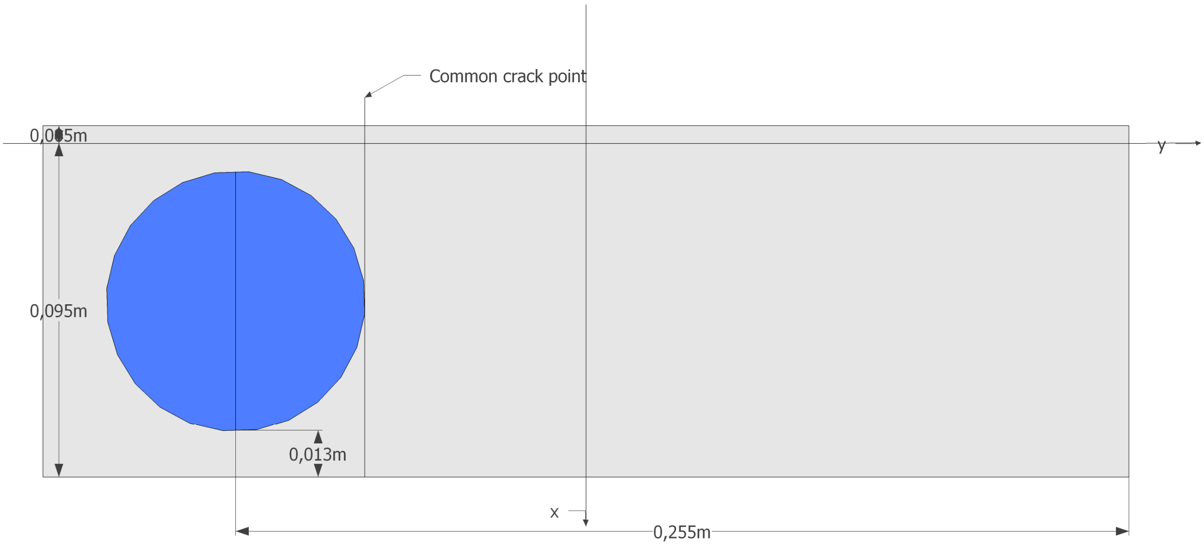


Figure 47 - Common crack point

All recent test results have been corrupted by cracking of concrete. In order to get good results from the ice abrasion test laboratory the cracking problem needs to be solved. Testing the strength of the old concrete samples may reveal that concrete is damaged and is no longer suitable for testing. If strength testing shows significant weakness of the old concrete, new samples with sufficient strength has to be made in order to get good abrasion data. If concrete strength appears to be sufficient, the problem is caused only by the tilting of the concrete.

Tilting of the concrete sample is an unwanted effect and should be fixed before more tests are performed at the laboratory. Concrete bedding, bearings and load sensors needs to be dismantled and inspected. If the parts cannot be repaired or replaced so no vertical movement of the concrete is allowed, a remodeling of the test apparatus should be considered. Placing a vertical load cell above the ice cylinder will remove the need for load cells underneath the concrete and possibly make it easier to make bedding which not plunges.

6. Conclusion

The literature study has shown me that ice abrasion is a complex problem. Many different factors contribute to the abrasion. Getting to know these factors has given a better understanding of ice abrasion .

Due to all the different factors involved in ice abrasion studies, different studies has found unlike results for the same problem. These differences may have occurred due to some unlike factors not being accounted for. When experimenting on ice abrasion good control over the variables is a necessity in order to get comparable and reliable data.

Working in the laboratory has proven to be very time consuming and unforeseen events has a tendency to show up. Originally the difference in abrasion rate for identical concrete with different initial treatment was to be examined. All four concrete samples cracked during testing causing abrasion measurement to give unreliable data. Testing instead revealed a possible problem with the test equipment. Improvements of test equipment have been evaluated. The outcome of a laboratory experiment is not always what you expect it to be. Nevertheless laboratory experience has been great learning, even though no sensible results came from the experiments.

Figure list

Table list

References

1. Hara, F., Takahashi, Y. and Saeki, H., *Evaluation of test methods of abrasion by ice movements on the surface of reinforced concrete structures.* Proceedings of the International Conference on Concrete under Severe Conditions, 1995. 1: p. 475 - 484.

2. Tyson, N.d. *Water, Water*. 1998; Available from: http://www.haydenplanetarium.org/tyson/read/1998/05/01/water-water.

3. PETROVIC, J.J., *Review*

Mechanical properties of ice and snow. JOURNAL OF MATERIALS SCIENCE 38, 2003.

4. Anderson Don L., W.F.W., *A Theoretical Analysis of Sea-Ice Strength.* Transactions, American Geophysical Union, 1958. 39(4).

5. P. Barnes, D.T., F.R.S. and J.C.F. Walker, *The friction and creep of polycrysalline ice.* 1971.

6. S. Løset, K.S., O.T. Gudmestad, P. Strass, E. Michalenko, and T.K. R. Frederking, *Comparison of the physical environment of some Arctic seas.* 1999(Cold Regions Science and Technology 29 1999. 201–214).

7. Wikipedia. *Cement*. Available from: http://en.wikipedia.org/wiki/Concrete.

8. Lomborg, B., *The Skeptical Environmentalist: Measuring the Real State of the World*2001. 138.

9. Esko Sistonen, M.L., Jari Puttonen, *Abrasion of concrete by ice.* Ice Abrasion Workshop 2007: p. 5 - 15.

10. Australia, C.C.A. *Concrete Basics*. Available from: http://www.concrete.net.au/publications/pdf/concretebasics.pdf.

11. Cement.org. *High-Strength Concrete*. Available from: http://www.cement.org/basics/concreteproducts_histrength.asp.

12. Elkem. *Frost resistance*. Available from: http://www.concrete.elkem.com/dav/6bd5f32a1f.pdf.

13. Huovinen, S., *Abrasion of Concrete Structures by Ice.* CEMENT and CONCRETE RESEARCH, 1993. 23: p. 69 - 82.

14. P.O. Moslet, H.A.M., *Effect of Surface Friction and Concrete Abrasion on Global Ice Load.* WORKSHOP Ice Abrasion on Concrete Structures, 2008: p. 125 - 127.

15. Huovinen, S., *Abrasion of concrete by ice in arctic sea structures.* VTT Publications 62, (Doctoral thesis), 1990.

16. Lev Kim assoc. prof., D.o.h., buildings and structures and R.D.d. Hydrotex, *23. august presentation by Lev Kim.ppt.*

17. Saeki, H., *Mechanical Properties Between Ice and Various Materials Used in Hydraulic Structures; The Jin S. Chung Award Lecture, 2010.* 2010.

18. Itoh, Y., Yoshida, A., Tsuchyia, M., Katoh, K., Sasaki, K. Seaki, H., *An Experimental Study on Abarsion of Concrete due to Sea Ice.* 1988: p. 61 - 68.

19. Itoh, Y., Seaki, H., Tanaka, Y., *Estimation Method for Abarasion of Concrete Structures Due to Sea Ice Movement.* 1994. 2: p. 545 - 552.

20. Hanada, M., Ujihir, M., Hara, F., Saeki, H. , *Abrasion Rate of Various Materials Due to the Movement if Ice Sheets.* 1996.

21. Hara, F., Saeki, H., Sato, M., Takahashi, Y., Tachibana, H., *Prediction of the degree of abrasion of bridge piers by fresh water ice and the protective measures.* Proceedings of the International Conference on Concrete under Severe Conditions, 1995. 1: p. 484 - 494.

22. Janson, J.E., *Long Term Resistance of Concrete Offshore Structures in Environment.* 7th International Conference on Offshore Mechanics and Arctic Engineering., 1988. 3: p. 225 - 231.

23. LabView. *What is NI Labview*. Available from: http://www.ni.com/labview/whatis/.

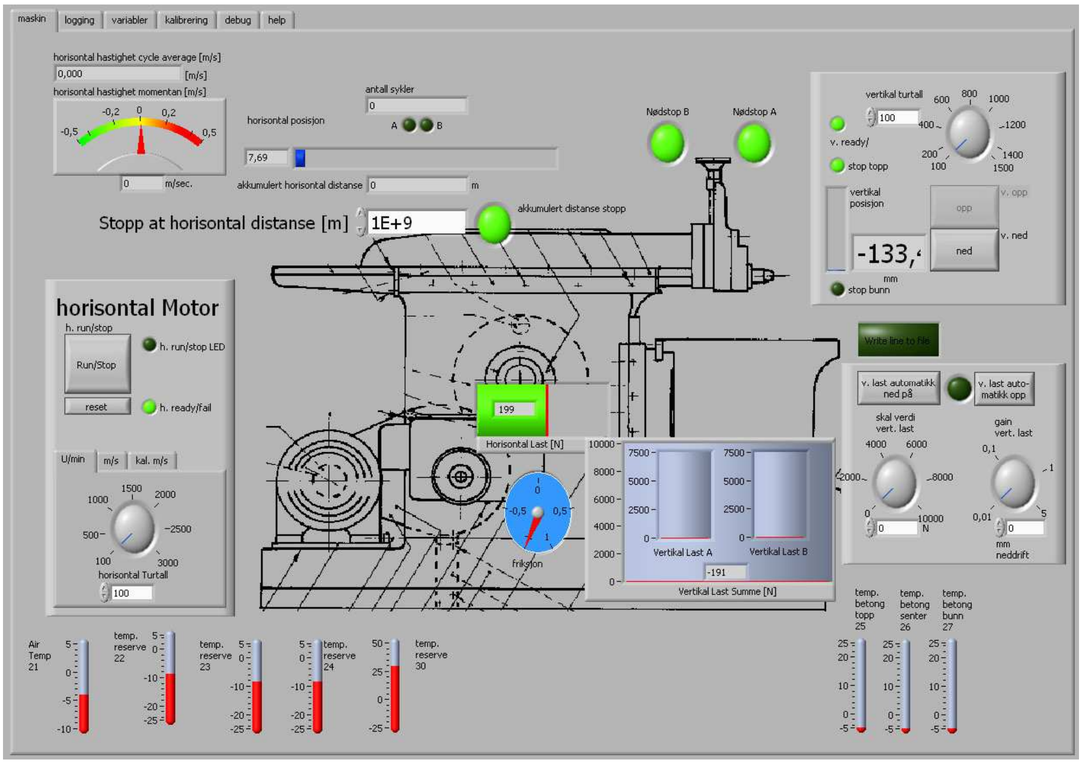
24. Manual, A.U. *atos_v6_en_rev-c.pdf*.

25. Møen, E., *Example files on test computer at NTNU Ice abrasion lab.*

26. Møen, E. *Average abrasion depth for w/c = 0,60 after 500 meters*. 2009. Abrasion Number Ranking_wc_06_after_500m_eff_sliding_dist, 1.

Appendix A, screenshots from LabView

Following is the 6 different views in the NTNU ice abrasion laboratory LabView program:



horisontal hastighet cycle average [m/s] 0,000 [m/s]

antall sykler 0

horisontal posisjon 7,69

akkumulert horisontal distanse 0 m

Stopp at horisontal distanse [m] 1E+9

vertikal turtall 100

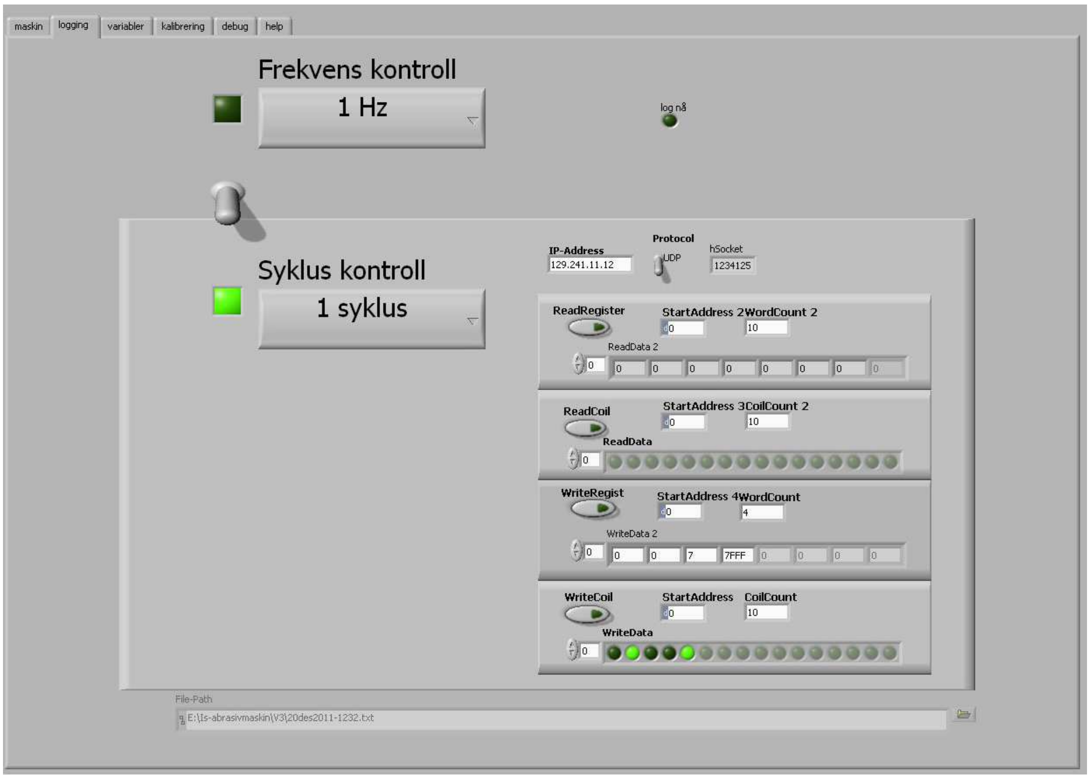
vertikal posisjon -133,4 mm

Horisontal Last [N] 199

Vertikal Last Summe [N] -191

horisontal Turtall 100

Figure 48 -Labview main window, machine



Frekvens kontroll 1 Hz

Syklus kontroll 1 syklus

IP-Address 129.241.11.12

Protocol UDP

hSocket 1234125

StartAddress 2 0 WordCount 2 10

ReadData 2: 0 | 0 0 0 0 0 0 0 0

StartAddress 3 0 CoilCount 2 10

ReadData 0

StartAddress 4 0 WordCount 4

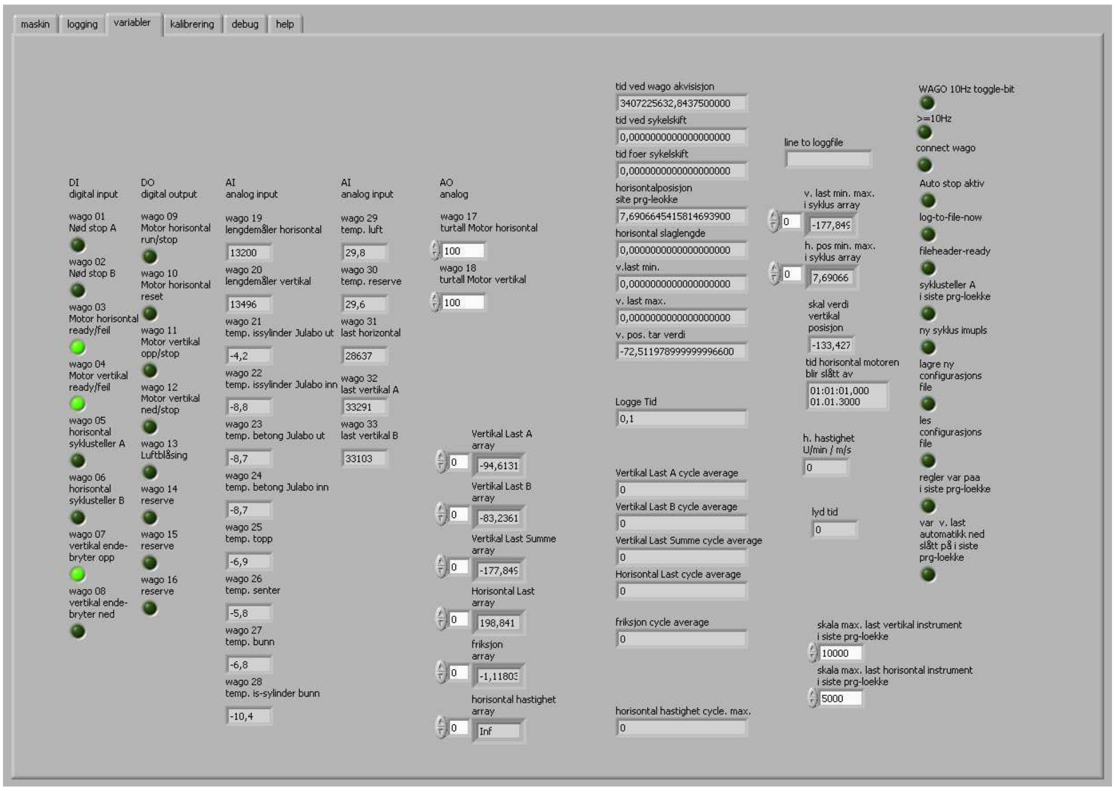
WriteData 2: 0 | 0 0 7 7FFF 0 0 0 0

StartAddress 0 CoilCount 10

WriteData 0

File-Path E:\Is-abrasivmaskin\V3\20des2011-1232.txt

Figure 49 - Labview logging



AI
analog input

wago 19
lengdemåler horisontal
13200

wago 20
lengdemåler vertikal
13496

wago 21
temp. issylinder Julabo ut
-4,2

wago 22
temp. issylinder Julabo inn
-8,8

wago 23
temp. betong Julabo ut
-8,7

wago 24
temp. betong Julabo inn
-8,7

wago 25
temp. topp
-6,9

wago 26
temp. senter
-5,8

wago 27
temp. bunn
-6,8

wago 28
temp. is-sylinder bunn
-10,4

AI
analog input

wago 29
temp. luft
29,8

wago 30
temp. reserve
29,6

wago 31
last horizontal
28637

wago 32
last vertikal A
33291

wago 33
last vertikal B
33103

AO
analog

wago 17
turtall Motor horisontal
100

wago 18
turtall Motor vertikal
100

Vertikal Last A
array
0
-94,6131

Vertikal Last B
array
0
-83,2361

Vertikal Last Summe
array
0
-177,849

Horisontal Last
array
0
198,841

friksjon
array
0
-1,11803

horisontal hastighet
array
0
Inf

tid ved wago akvisisjon
3407225632,8437500000

tid ved sykelskift
0,0000000000000000000

tid foer sykelskift
0,0000000000000000000

horisontalposisjon
site prg-leokke
7,6906645415814693900

horisontal slaglengde
0,0000000000000000000

v.last min.
0,0000000000000000000

v. last max.
0,0000000000000000000

v. pos. tar verdi
-72,5119789999999996600

Logge Tid
0,1

Vertikal Last A cycle average
0

Vertikal Last B cycle average
0

Vertikal Last Summe cycle average
0

Horisontal Last cycle average
0

friksjon cycle average
0

horisontal hastighet cycle. max.
0

line to loggfile

v. last min. max.
i syklus array
0
-177,849

h. pos min. max.
i syklus array
0
7,69066

skal verdi
vertikal
posisjon
-133,427

tid horisontal motoren
blir slått av
01:01:01,000
01.01.3000

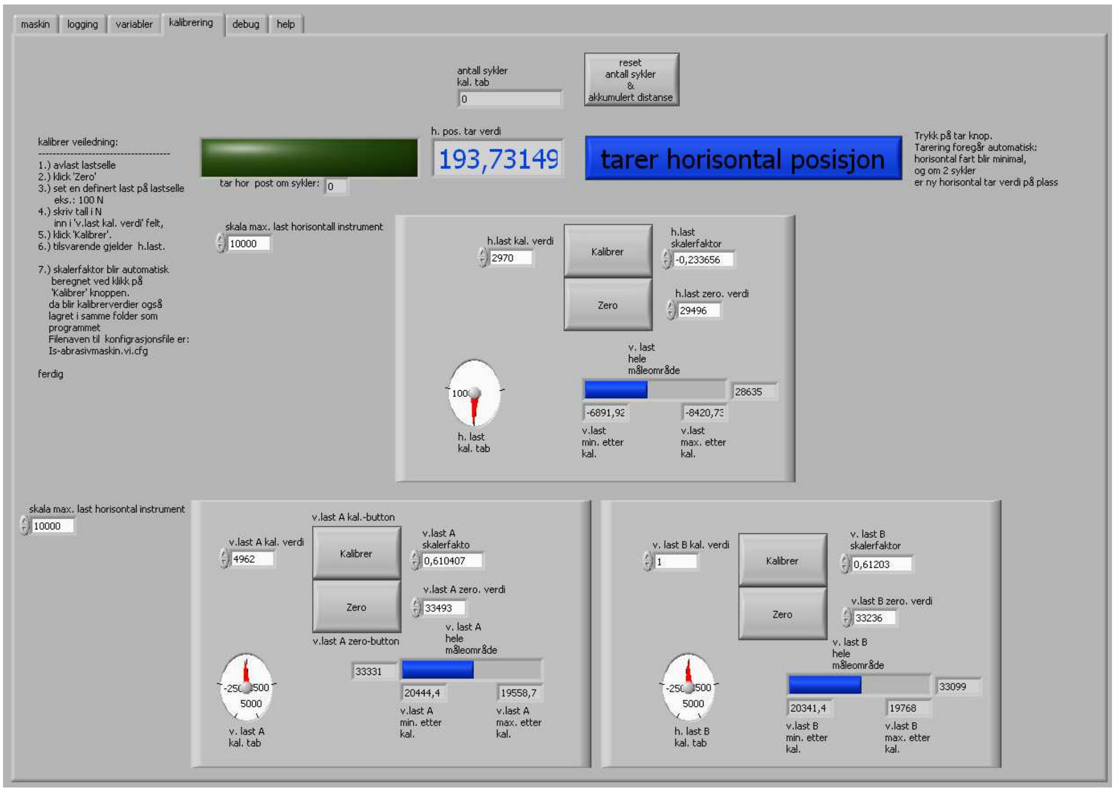
h. hastighet
U/min / m/s
0

lyd tid
0

skala max. last vertikal instrument
i siste prg-loekke
10000

skala max. last horisontal instrument
i siste prg-loekke
5000

Figure 50 - Labview variables



antall sykler
kal. tab
0

kalibrer veiledning:

1.) avlast lastselle
2.) klick 'Zero'
3.) set en definert last på lastselle
eks.: 100 N
4.) skriv tall i N
inn i 'v.last kal. verdi' felt,
5.) klick 'Kalibrer'.
6.) tilsvarende gjelder h.last.

7.) skalerfaktor blir automatisk
beregnet ved klikk på
'Kalibrer' knoppen.
da blir kalibrerverdier også
lagret i samme folder som
programmet
Filenaven til konfigrasjonsfile er:
Is-abrasivmaskin.vi.cfg

ferdig

tar hor post om sykler: 0

h. pos. tar verdi
193,73149

Trykk på tar knop.
Tarering foregår automatisk:
horisontal fart blir minimal,
og om 2 sykler
er ny horisontal tar verdi på plass

skala max. last horisontall instrument
10000

h.last kal. verdi
2970

h.last
skalerfaktor
-0,233656

h.last zero. verdi
29496

v. last
hele
måleområde
28635

v.last
min. etter
kal.
-6891,92

v.last
max. etter
kal.
-8420,73

skala max. last horisontal instrument
10000

v.last A kal. verdi
4962

v.last A
skalerfakto
0,610407

v.last A zero. verdi
33493

v. last A
hele
måleområde
33331

v.last A
min. etter
kal.
20444,4

v.last A
max. etter
kal.
19558,7

v. last B kal. verdi
1

v. last B
skalerfaktor
0,61203

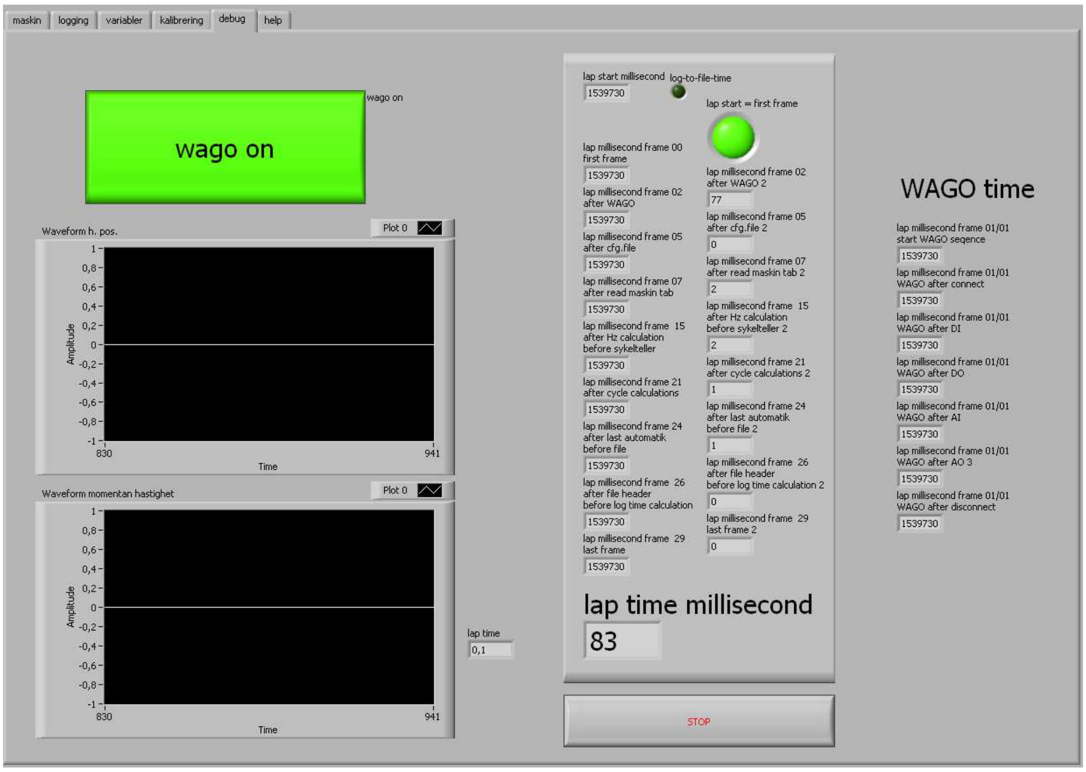
v.last B zero. verdi
33236

v. last B
hele
måleområde
33099

v.last B
min. etter
kal.
20341,4

v.last B
max. etter
kal.
19768

Figure 51 – Labview Calibrating



lap time
0,1

lap start millisecond
1539730

lap millisecond frame 00
first frame
1539730

lap millisecond frame 02
after WAGO
1539730

lap millisecond frame 05
after cfg.file
1539730

lap millisecond frame 07
after read maskin tab
1539730

lap millisecond frame 15
after Hz calculation
before sykelteller
1539730

lap millisecond frame 21
after cycle calculations
1539730

lap millisecond frame 24
after last automatik
before file
1539730

lap millisecond frame 26
after file header
before log time calculation
1539730

lap millisecond frame 29
last frame
1539730

lap millisecond frame 02
after WAGO 2
77

lap millisecond frame 05
after cfg.file 2
0

lap millisecond frame 07
after read maskin tab 2
2

lap millisecond frame 15
after Hz calculation
before sykelteller 2
2

lap millisecond frame 21
after cycle calculations 2
1

lap millisecond frame 24
after last automatik
before file 2
1

lap millisecond frame 26
after file header
before log time calculation 2
0

lap millisecond frame 29
last frame 2
0

lap time millisecond
83

WAGO time

lap millisecond frame 01/01
start WAGO seqence
1539730

lap millisecond frame 01/01
WAGO after connect
1539730

lap millisecond frame 01/01
WAGO after DI
1539730

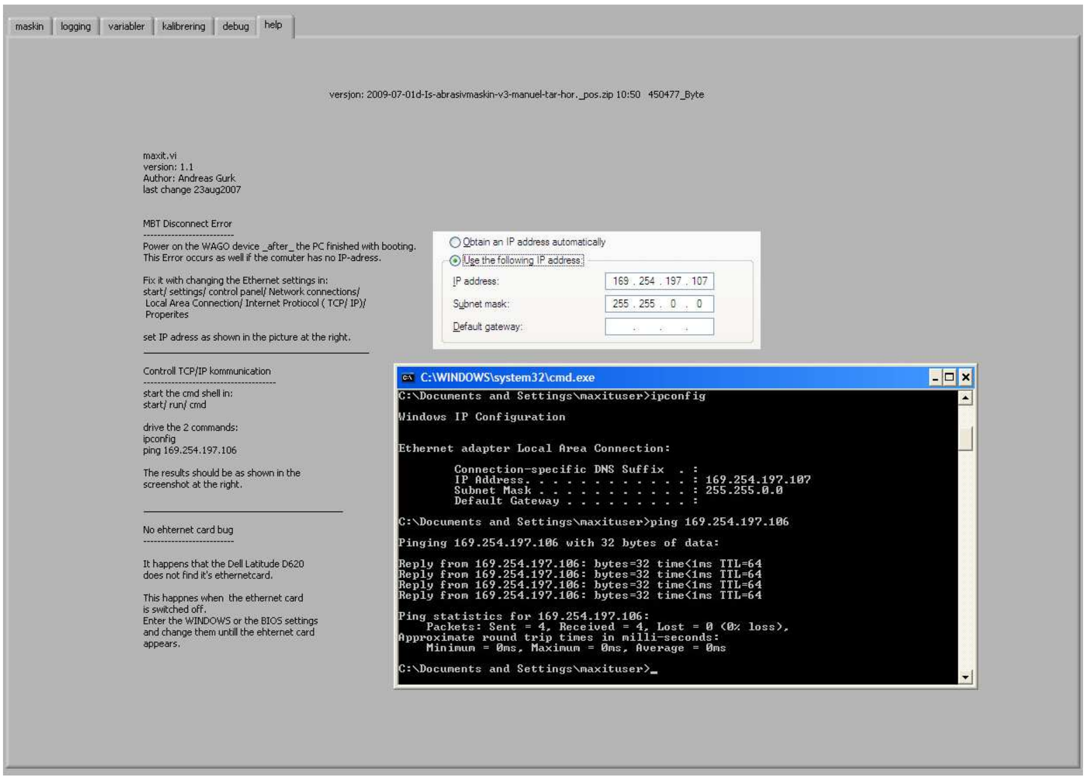
lap millisecond frame 01/01
WAGO after DO
1539730

lap millisecond frame 01/01
WAGO after AI
1539730

lap millisecond frame 01/01
WAGO after AO 3
1539730

lap millisecond frame 01/01
WAGO after disconnect
1539730

Figure 52 – Labview debug



versjon: 2009-07-01d-Is-abrasivmaskin-v3-manuel-tar-hor._pos.zip 10:50 450477_Byte

maxit.vi
version: 1.1
Author: Andreas Gurk
last change 23aug2007

MBT Disconnect Error

Power on the WAGO device _after_ the PC finished with booting.
This Error occurs as well if the comuter has no IP-adress.

Fix it with changing the Ethernet settings in:
start/ settings/ control panel/ Network connections/
Local Area Connection/ Internet Protiocol (TCP/ IP)/
Properites

set IP adress as shown in the picture at the right.

○ Obtain an IP address automatically
● Use the following IP address:
IP address: 169 . 254 . 197 . 107
Subnet mask: 255 . 255 . 0 . 0
Default gateway: . . .

Controll TCP/IP kommunication
----
start the cmd shell in:
start/ run/ cmd

drive the 2 commands:
ipconfig
ping 169.254.197.106

The results should be as shown in the
screenshot at the right.

C:\WINDOWS\system32\cmd.exe

```
C:\Documents and Settings\maxituser>ipconfig

Windows IP Configuration


Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        IP Address. . . . . . . . . . . . : 169.254.197.107
        Subnet Mask . . . . . . . . . . . : 255.255.0.0
        Default Gateway . . . . . . . . . :

C:\Documents and Settings\maxituser>ping 169.254.197.106

Pinging 169.254.197.106 with 32 bytes of data:

Reply from 169.254.197.106: bytes=32 time<1ms TTL=64
Reply from 169.254.197.106: bytes=32 time<1ms TTL=64
Reply from 169.254.197.106: bytes=32 time<1ms TTL=64
Reply from 169.254.197.106: bytes=32 time<1ms TTL=64

Ping statistics for 169.254.197.106:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 0ms, Average = 0ms

C:\Documents and Settings\maxituser>_
```

No ehternet card bug

It happens that the Dell Latitude D620
does not find it's ethernetcard.

This happnes when the ethernet card
is switched off.
Enter the WINDOWS or the BIOS settings
and change them untill the ehternet card
appears.

Figure 53 - Labview help

Appendix B, Maintenance of abrasion machine after down period

All equipment that has not been used for a while is often in need of maintenance. For the ice abrasion lab at NTNU the following has been done in order to get the machine ready for testing again.

Re lubricate moving parts in order to ensure smooth movement and keep the appartus corrosion free.

Adjusting of the insulated cylinder (ice compartment). It is important that this cylinder is as close to the concrete specimen as possible. During the down time this cylinder had become offset with a few millimeters and abraded on the concrete.

Julabo heating/cooling circulation was bad in the in the concrete bedding and complete none flowing in the ice compartment. All couplings were opened up and corrosion and dirt was removed. The two circuits were blown clean with compressed air.

Testing of temperature sensors, all seemed to be ok

Horizontal movement tested ok.

Vertical movement tested ok.