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Published in:

International Conference on Materials, Systems and Structures in Civil Engineering

Publication date:

2016

Document Version

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):

Sigvardsen, N. M., Bonnerup, A. H., & Ottosen, L. M. (2016). Recycled fishing nets as reinforcement of existing concrete structures. In International Conference on Materials, Systems and Structures in Civil Engineering: Conference workshop on Cold Region Engineering (pp. 17-26). Technical University of Denmark, Department of Civil Engineering. (B Y G D T U. Rapport; No. Byg R-352).

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RECYCLED FISHING NETS AS REINFORCEMENT OF EXISTING CONCRETE STRUCTURES

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Abstract

Large amounts of fishing nets are discarded every year polluting the oceans with plastic fibers on a global scale. Due to the big fishing industry in Greenland an alternative use for discarded fishing nets would have a decreasing effect on the amount of marine litter in the Arctic. A use for discarded fishing nets could be as fiber-reinforced polymer (FRP) composites for near surface mounted reinforcement (NSMR). NSMR prolongs the lifetime of existing structures, and thus reduces the amount of materials transported to Greenland, reducing CO₂-emission and expenses. The effect of NSMR FRP bars made from discarded fishing nets is examined with regards to formation of cracks, load and failure of the beam. Results show a tendency for beams with NSMR FRP bars to prolong the linear elastic region, thus postponing the formation of cracks. Further, a tendency for reducing formation of cracks in the shear zone and resisting a higher load, is seen. A method for casting NSMR FRP bars with discarded fishing nets is developed, evaluated and suggestions for improvements have been made. This study paves the way for the possibility of using discarded fishing nets as NSMR FRP bars, but requires further studies.

Key words: Arctic, marine litter, sustainability, near surface mounted reinforcement, fiber-reinforced polymer composites, tensile testing, casting of beams

1. Introduction

In recent years there has been a growing concern regarding the state of the ocean ecology due to marine litter. The United Nations Environment Programme report of 2009 estimated $6.4 \cdot 10^6$ metric tonnes of ocean litter is discarded into the oceans pro anno. 10% of this is estimated to be discarded fishing nets, thus 640,000 metric tonnes of fishing nets end up as free floating ocean waste annually [1]. Fishing nets are made from plastic fibers, which do not biodegrade, but undergo a physical and chemical degrading process. The process of degrading depends on

external factors such as salinity, temperature and UV-radiation [2]. When the plastic fibers are degraded into micro plastic it can be absorbed in plankton and thereby pollute the entire food chain. Furthermore, some of the chemicals used in the manufacturing of plastic contain hormones which are dissolved in the oceans [2]. Therefore, it would be beneficial for the environment to find a new use for the discarded fishing nets, such as recycling as reinforcement in concrete.

23% of the average import measured by BNP to Greenland from 1988 till 2012 is construction materials [3]. By utilizing materials already found in Greenland as substitution or addition to conventional construction materials, such as discarded fishing nets used as reinforcement, the cost and CO₂-emission of transportation can be reduced. Further, fishing nets are made of polyethylene or nylon which are non-corrosive materials, making the concrete resistant to corrosion.

In order to utilize the already existing materials in Greenland, this study investigates the use of discarded fishing nets as NSMR FRP bars in concrete beams.

1.1 Fishing nets in Greenland

Several different types of fishing nets are found in Greenland, where polyethylene nets for shrimp fishing is the most common kind according to Statistic Greenland [3]. Fishing nets are often lost or discarded in the oceans, for the benefit of replacing valueless outworn fishing nets with shrimp when returning to shore. When the fishing nets have been discarded they either degrade or eventually sweep ashore. In the oceans, fishing nets are exposed to physical deterioration and fragmentation which causes degrading of the fishing nets into micro plastics depending on the amount of exposure to sunlight, salinity and temperature [2]. Some fishing nets are brought to the landfill which may influence the composition of the fishing nets chemically. Additionally, degrading by sunlight, salinity and temperature are expected to have an influence on the composition. The fishing nets investigated for this article are found at the landfill in Sisimiut.

1.2 Discarded fishing nets as reinforcement

There are many possible applications for the use of fishing nets as reinforcement of concrete. FRP bars for near-surface mounted reinforcement were tested and investigated at DTU Lyngby, Denmark. NSMR FRP bars are most commonly made from carbon fibers used for repair and rehabilitation of existing concrete structures e.g. if the structure is under reinforced in the tensile zone, while the remaining part of the cross section has sufficient strength [4]. FRP bars made from fishing nets used as NSMR are expected to reduce the formation of cracks and are thus placed in the surface of the tensile zone [5].

This topic of fishing net as reinforcement in concrete and thus as NSMR FRP bars is still fairly unexplored [6] and therefore the main focus of this study will be on method and execution of tests. The tensile strength of fishing nets made from polyethylene is 240 MPa [7], which is lower than the tensile strength of steel [8] and the tensile strength of carbon fibers [9]. Therefore, the pattern of cracks, fracture and methods for casting and testing will be evaluated rather than the tensile strength.

2. Materials and methods

Casting beams with FRP bars made from fishing net was executed in five steps: binding shear

steel reinforcement; casting of the concrete beams with recess lists meant for replacement with FRP bars; casting of the FRP bars from stings of fishing nets and epoxy; embedding FRP bars into concrete beams with epoxy and finally testing of all beams. The method for casting beams with NSMR FRP bars is inspired by the method described in Rankovic et al. [4] and Lorenzis and Nanni [5].

2.1 Binding of steel reinforcement

Steel stirrups and longitudinal reinforcement is placed in the beam according to figure 1. The grey areas in figure 1 represent the FRP bars.

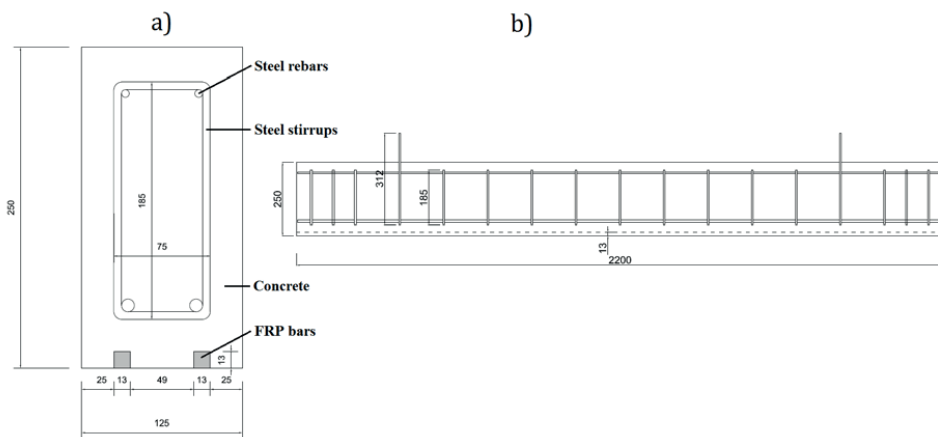


Figure 1: a) Cross section of beam b) longitudinal cross section. All measurements are in mm.

The FRP bars in the beam are chosen to have a diameter of 10 mm. In order to make space for epoxy, insuring bonding between the FRP bars and the cured concrete, wooden lists of 13 x 13 mm are embedded in the concrete. The covering layer is 25 mm. The stirrups have a diameter of 6 mm which are placed with a distance of 150 mm and 75 mm near the supports. The steel reinforcement is calculated to be balanced [10]. In the bottom of the mould two wooden lists are placed with a distance of approximately 50 mm and secured with duct tape. When the beams are cured, the wooden lists are removed and replaced with FRP bars.

2.2 Casting of beams

The beams are casted with 30 MPa concrete and cured for 14 days. The recipe used for mixing the concrete can be seen in table 1.

Table 1: Concrete mixture for 80 l of concrete

Water [kg]	16.0
Basis cement [kg]	22.8
Sand 0-4 mm [kg]	70.7
Gravel 4-8 mm [kg]	19.5
Gravel 8-16 mm [kg]	59.1

The mixer used for mixing the concrete has a volume of 100 l. The volume of one beam is approximately 69 l, and therefore it is only possible to cast one beam at a time, which can be a source of error. Leftover concrete was used to cast cylinders. The concrete is mixed as follows:

- All dry ingredients are put in 100 l mixing bowl in the following order: all gravel, half the sand, all of the cement and the remaining half of the sand.
- All dry ingredients are mixed for 1 minute.
- Water is added, retaining approximately 3 l.
- The dry ingredients and the water are mixed for 3 minutes.
- Based on a visual examination of the texture of the concrete, some of the retained water was added if needed. When the texture is satisfying, the concrete is ready for casting.

The mould for beams and cylinders were half filled with the concrete mixture and vibrated once to reduce air content. The moulds were filled to the top, surfaced and vibrated again. A total of four beams were cast: three containing wooden lists for removal and replacement with FRP bars (Beam 1, 2 and 3) and a reference beam without lists (Beam REF).

The beams were left to set for 24 hours in the mould, where after the beams were demoulded and lowered into water to assist the hydration. The beams were left in water for additional 9 days. The beams were hoisted from the water 4 days before testing to make the recesses dry before embedding the FRP bars with epoxy. This was to ensure the necessary bonding between the epoxy and the concrete. This adds up to a total of 14 days of curing.

2.3 Casting of FRP bars

Strings of fishing net were cut along the knots (from the fishing nets brought from Greenland), see figure 2. Moulds were made in wood with milled recesses, 10 x 10 mm, and coated with duct tape, in order to make the epoxy easily released from the mould, see figure 2. The strings of fishing net were tensioned in the mould by two end pieces, and the moulds were filled with an epoxy mixture. This epoxy is a two-component glue, consisting of a resin and a hardener, with a high strength. The epoxy mixture used for casting FRP bars consists of a resin: 'Mellemløst epoxy harpiks' and a hardener: 'Modificeret Polyamidoamin hærder' in the ratio 1.7:1 [11], see figure 2.

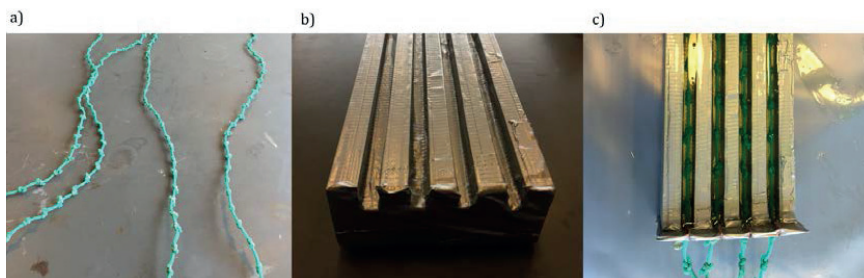


Figure 2: a) Strings of fishing net b) moulds coated with duct tape prepared for FRP bars c) cast FRP bars.

2.4 Embedding FRP bars in concrete beams

The FRP bars were embedded in the cured concrete beams with an epoxy mixture of resin: 'PC 5800 BL A' and hardener: 'PC 5800 BL B' in the ratio 2.2:1 [12], see figure 3.

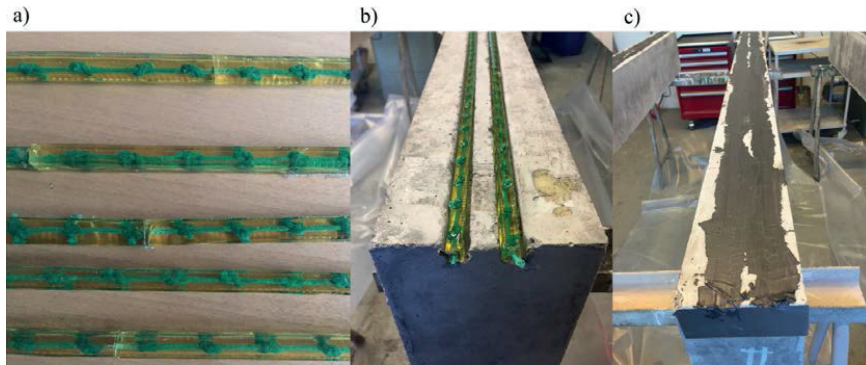


Figure 3: *a)* Hardened FRP bars *b)* FRP bars in recess prepared for casting *c)* beam with embedded FRP bars in a epoxy mixture of resin: 'PC 5800 BL A' and hardener: 'PC 5800 BL B'.

2.5 Tensile testing of beams with FRP bars

All four beams were tested in a force controlled deflection machine performing four point bending, see figure 4.

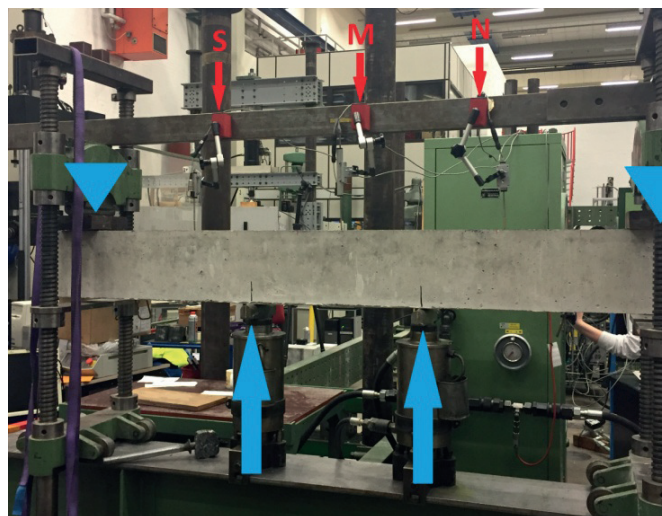


Figure 4: Upside-down test rig set-up with three electronic displacement gauges, gauge South (S), gauge Middle (M) and gauge North (N).

Two hydraulic pistons applied load until failure and three electronic displacement gauges measured the deflection of the beams at quarter points. All cracks were photo documented for

later analysis.

A test rig with four point bending creates pure moment between the two hydraulic pistons, and moment and shear strength between the hydraulic pistons and the supports, see figures 5 and 7 [8]. Therefore, with this type of test rig, it is possible to distinguish between cracks caused by shear strength and moment and thus analyze the effect of the FRP bars.

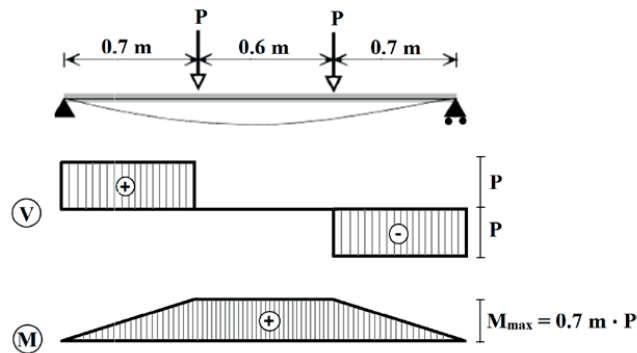


Figure 5: Theoretical set-up, shear and moment distribution.

3. Results and Discussion

3.1 Material parameters

The cylinders were tested as a uniaxial compression test according to DS/EN 12390-3 [13], and the average strength was 25 MPa. This is an acceptable value after 14 days of curing [14].

The steel reinforcement chosen for the beams have a characteristic yield stress of 550MPa and a characteristic tensile strength of 650MPa [15].

The fishing net used for FRP bars is made of polyethylene, braided, section 5.5 from Vónin [7], with a breaking strength of 120 kgf (kilogram force) [7]. The fishing net has a diameter of 2.5 mm, and thus the tensile strength of the fishing net can be calculated from (1).

$$\frac{m[\text{kgf}] \cdot g [\text{m/s}^2]}{A [\text{mm}^2]} = \frac{120 \text{ kgf} \cdot 9.81 \text{ m/s}^2}{\pi \left(\frac{2.5 \text{ mm}}{2}\right)^2} = 240 \text{ MPa} \quad (1)$$

This results in a tensile strength of 240 MPa for the applied fishing net. The tensile strength may be lower due e.g. temperature [16], abrasion from its original use and storage in landfills.

3.2 Cracks and fracture

Figure 6 shows an example of comparison between a beam with NSMR FRP bars and the reference beam.

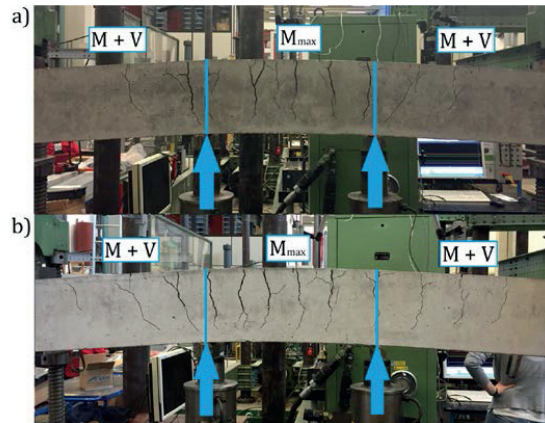


Figure 6: *a)* Beam 3 after maximum load is reached *b)* Beam REF after maximum load is reached.

As described in section 2.5 the shear zone and moment zone are found between the supports and the hydraulic pistons and only moment is found between the two hydraulic pistons. Figure 6 shows that the failure occurs in the moment zone for both beam 3 and beam REF. The cracks in beam 3 are primarily found in the moment zone compared to beam REF, where the cracks are distributed over both shear and moment zones. This supports the tendency that the FRP bars have a positive effect on the shear strength and bearing capacity of the beam. Furthermore, it is seen that the addition of FRP bars does not influence the formation of cracks caused by moment. It is clear that beam REF in figure 6b shows more visible cracks compared to beam 3 in figure 6a.

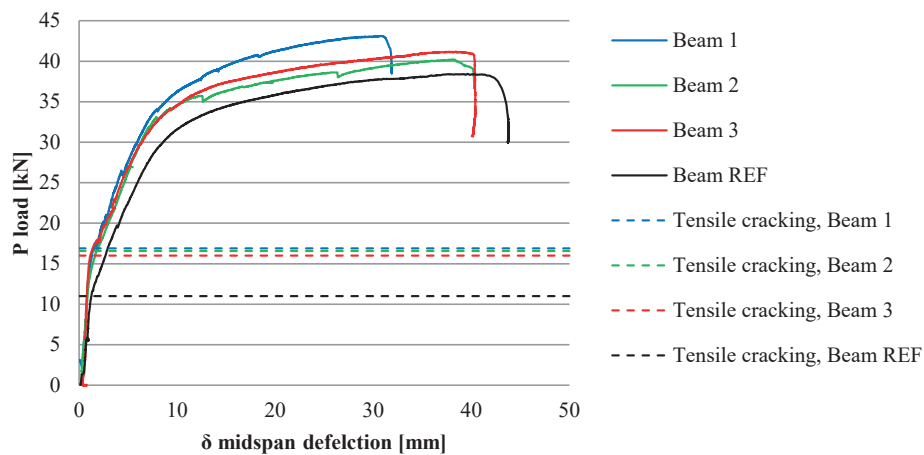


Figure 7: Load-deflection curve

3.3 Load evaluation

Figure 7 shows the load-deflection curve for the midspan deflection.

The curves for Beam 1, 2 and 3 generally attain a higher load, compared to beam REF. This result correlates well with the results attained in Rankovic et al. [4]. The points of tensile cracking for Beam 1, 2 and 3 are offset and thus the plastic region is reached at a higher load. This causes the linear elastic region for NSMR FRP bars to extend beyond the linear elastic region for beam REF, which delays the formation of visible cracks when using FRP bars [8].

When NSMR FRP bars are added to the beams, the moment capacity, thus F_{max} , increases, as visualized in figure 6.

3.4 Evaluation of methods and recommendations

The method for casting FRP bars in concrete beams is evaluated and based on the experience from this study, recommendations to future research is described.

3.4.1 Casting of beams and FRP bars

In the casting process the following observations were made. When casting the beams it is important to fix the wooden list properly in the mould before casting. If the lists are not fixed adequately the concrete will flow under the list and thus change the thickness of the covering layer. This will also make the lists harder to remove after curing. If possible, it would be recommended to mill recesses directly in the cured concrete beams. Small variations in the w/c-ratio was observed, but was concluded not to have an influence on the test results.

A new type of mould for casting FRP bars should be developed. A suggestion could be to assemble the mould with screws instead of milling recesses. This would facilitate the demoulding process of the FRP bars and reduce the risk of cracking the FRP bars. Furthermore, it is important to cover the mould in tape with a smooth, plastic surface. In this study duct tape was used, which stuck to the FRP bars when demoulding and is not recommendable.

Furthermore, it would facilitate the working process if an epoxy mixture with a lower viscosity was accessible as a replacement of the epoxy mixture of 'PC 5800 BL A' and 'PC 5800 BL B'. This would make the process of fixing the FRP bars in the recesses easier.

3.4.2 Tensile testing

A force controlled deflection machine was used for testing the effect of the FRP bars in relation to the development of visible cracks in the beams. When using a force controlled deflection machine the load continues to rise without regards to the deformation of cracks and the weakening of the beam. Furthermore, the force controlled deflection machine causes the beam to deflect unevenly by causing a bigger deflection at the weakest part of the beam. If using a deflection controlled machine for testing the effect for FRP bars it would be possible to control the force with respect to the deflection and formation of cracks. This would make it possible to examine the response of the cracks on the application of load. This would give the deformation curve a post peak, which shows the starting point of crack formation.

3.4.3 Implementation in Greenland

There are pros and cons connected with implementing FRP bars as near-surface mounted reinforcement in Greenland. The aim is to utilize already existing materials in Greenland in order to reduce the CO₂-emmission caused by transportation, reduce the financial expenses in relation to import of construction materials and reduce the otherwise continuing pollution of

oceans.

FRP bars are used as NSMR for prolonging the lifetime of already existing concrete structures and thus the implementation of FRP bars would reduce the frequency of transporting building materials for new constructions to Greenland. However, it would be necessary to transport epoxy to Greenland, but in much smaller amount than the amount of materials needed for a whole new construction.

When casting FRP bars the fishing nets have to be shipped ashore. Currently the fishing nets are thrown overboard and the released space is replaced by shrimp or fish. Therefore, there has to be an economic benefit for the fishermen to bring the worn out fishing nets ashore, thus reducing the amount of marine litter. This could be in the form of a deposit system.

3.5 Future research

In order to implement FRP bars with fishing nets a mechanical analysis has to be conducted, along with a chemical analysis of the surface of the fishing nets. It would be relevant to study the yield point of the fishing net in relation to the yield point of steel in order to determine how they support each other. Alternatively to the method used in this article, the FRP bars can be cast by dipping strings of fishing nets into epoxy or a similar coating, multiple times. This will make the knots on the strings of fishing net larger and thus create larger anchors on the strings and increase the sealing effect. These anchors transfer tension and thereby contribute to reducing the formation of visible cracks.

4. Conclusion

By using discarded fishing nets as NSMR FRP bars reduces the amount of litter on the landfills and marine litter in the oceans, and thereby utilizing materials already found in Greenland. NSMR is used for repair and rehabilitation of existing buildings and thus postpone the need for new materials transported to Greenland.

The aim of the study was to develop a method for casting NSMR FRP bars with discarded fishing nets, execution beam testing with NSMR FRP bars and analyzing the patterns of visible cracks and fractures for beams with NSMR FRP bars.

Three beams were cast with stirrups, longitudinal reinforcement and NSMR FRP bars made from discarded fishing nets. One beam was cast as reference with only stirrups and longitudinal reinforcement. The beams were tested with four point bending. The influence of FRP bars are determined by visible crack patterns and load. The beams with NSMR FRP bars generally attain a higher load, and the point of cracking increases. This means the cracking of the beam is postponed, and it can further be concluded from the pattern of visible cracks, that the FRP bars reduce the cracks caused by shear strength. There is a tendency that the use of NSMR FRP bars, made of discarded fishing nets, has a positive effect on the formation of visible cracks. The results could benefit from using a deflection controlled bending machine instead of a force controlled bending machine, since this would give a more even distribution of visible cracks.

A chemical analysis and characteristic of the mechanical properties of the fishing nets should be made. Alternative methods can be used for casting FRP bars e.g. the strings of fishing nets could be dipped in epoxy or coating for the purpose of crating larger anchors to increase the sealing effect. If NSMR FRP bars are implemented in Greenland it would still require transportation of epoxy to Greenland, but in smaller scale compared to transporting materials for a whole new structure. In order to accommodate the issue of fishing nets being thrown

overboard, a deposit system could be implemented. An economical benefit of returning discarded fishing nets could reduce the amount of marine litter on a global level.

Acknowledgement

The authors would like to direct a special thanks to Associate Professor Jacob Wittrup Schmidt, PhD-student Ida Maria Gieysztor Bertelsen and concrete technician Per Leth for their great help along the project. Furthermore, the authors would like to acknowledge the technicians at DTU Byg for help with practical issues, Gunvor Marie Kirkelund and the Arctic Technology Center in general, for guidance regarding article writing and for information and assistance about fieldwork in Greenland.

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