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Materials, Systems and Structures in Civil Engineering

22-24 August 2016

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In pursuit of innovative and sustainable solutions for marine plastic waste, the Circular Ocean project seeks to inspire enterprises and entrepreneurs to realise the hidden opportunities of discarded fishing nets and ropes in the Northern Periphery & Arctic (NPA) region.

As increasing levels of marine litter is particularly pertinent to the NPA region, the Circular Ocean project will act as a catalyst to motivate and empower remote communities to develop sustainable and green business opportunities that will enhance income generation and retention within local regions.

Through transnational collaboration and eco-innovation, Circular Ocean will develop, share and test new sustainable solutions to incentivise the collection and reprocessing of discarded fishing nets and assist the movement towards a more circular economy.

Circular Ocean is led by the Environmental Research Institute, www.eri.ac.uk (Scotland), and is funded under the European Regional Development Fund (ERDF) Interreg VB Northern Periphery and Arctic (NPA) Programme http://www.interreg-npa.eu. It has partners in Ireland (Macroom E www.macroom-e.com), England (The Centre for Sustaibale Desgin www.cfsd.org.uk), Greenland (Arctic Technology Centre www.artek.byg.dtu.dk), and Norway (Norwegian University of Science and Technology www.ntnu.edu).

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Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

ENGINEERING PROPERTIES OF FIBRES FROM WASTE FISHING NETS

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Abstract

This study is part of the international project Circular Ocean and focuses on reducing marine plastic waste within the Northern Periphery and Arctic (NPA) region by developing new sustainable solutions for the reuse of discarded waste fishing nets.

Recycled plastic fibres from waste fishing nets of high-density polyethylene (HDPE) were investigated with respect to their engineering properties such as tensile strength and Young's modulus. Tensile tests were carried out on monofilament fibres from fishing nets in accordance with ASTM Standards and were performed on both new fibres and waste fibres from similar net types.

Waste fishing nets of the type "Braided Polyethylene" were collected at the dump-site in Sisimiut, Greenland, and are produced by Euronete and supplied by Vónin, which is the leading supplier of fishing gear in Greenland.

With this screening it is possible to evaluate the applicability of this type of discarded fishing nets as reinforcement in construction materials. The present paper focuses concrete materials and discusses how the fishing nets can be implemented in concrete in order to improve its properties.

1 Introduction

Plastic litter in the ocean environment is a constantly increasing problem. Dreadful estimates of the increasing quantities of marine plastic waste are being made these years, e.g. in 2050 the weight fraction plastic waste will be greater than the one of fishes in the oceans [1]. Regarding the fraction of lost or otherwise discarded fishing nets; it is estimated to around 10 % of the total global marine waste by volume [2]. The problem is as well worsening in the NPA region these years due to climate changes, more regular access to the Arctic Sea route and sea currents from the North Atlantic which carries a continuous supply of marine waste to the region [3].

International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

Fishing nets are commonly made of synthetic polymeric fibres such as high density polyethylene (HDPE), polyethylene terephthalate (PET) or polyamide (PA), materials which are non-biodegradable and typically neutrally buoyant [4]. For this reason, the discarded nets can drift long distances at variable depths within the oceans [5]. These so-called ghost nets is a problematic waste fraction in the marine environment since they can lead to entanglement of marine mammals, fishes, birds or active fishing gear [6].

Recent studies have shown that several types of plastic waste can be profitably employed in concrete materials [7]–[10], why the idea of using waste fishing nets as reinforcement occurred. The fishing net lines consist of either twisted or braided fibres, which are similar in shape to those used for fibre reinforcement of cementitious materials such as concrete. This would furthermore result in limited processing operations, which only includes cutting the nets down to the requested length.

Polymeric fibre types that have been tried in cementitious materials are acrylic, nylon, polyester, polyethylene and polypropylene [11]. For many of these fibers, there is little reported research or field experience, while others, especially polypropylene [9], [12]–[14], are found in commercial applications [11]. The main role of incorporating fibres in a cementitious matrix is to improve the toughness, impact resistance, and post-cracking behaviour and to control shrinkage cracking and permeability of the material [8], [10], [15], [16]. Important properties for fibres used as fibre reinforcement are the mechanical properties such as tensile strength, elongation strain and Young's modulus, thermal properties, deterioration in alkaline environments, bonding properties and the geometrical shape of the fibres. According to Banthia et al. [16], polyethylene is a hydrophobic polymer which is has excellent alkali resistant properties.

As a consequence of outdoor- and UV-exposure together with continuous load impacts, the properties of the fishing nets investigated in this study, have been impaired during use [17]–[19], why the properties of waste fibres are compared to those of new fibres.

The present paper focuses on an experimental determination of properties of HDPE fibres in order to determine whether the fibres are suitable for being used as fibre reinforcement of cementitious materials.

2   Materials and methods

2.1 Physical properties of HDPE fibres

Experimental investigations were performed on new and discarded HDPE fishing nets to evaluate the mechanical and physical, and thereby the differences in properties between new and discarded ones. The investigated nets were of the type Braided Polyethylene from Vónin, produced by Euronete and were collected at the dumpsite in Sisimiut, Greenland, after being

International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

used for shrimp bottom trawling for an unknown period of time. After collection, the nets were superficially cleaned in fresh water to remove residues and other impurities. The net type of polyethylene is among the most used types in the Greenlandic fishing industry [20]. Each line has a diameter of 2.5 mm [21] and consists of about 40 filament fibres with a diameter of 0.27-0.33 mm, which was measured by scanning electron microscope (SEM). For determination of the density, the pycnometer method was used.

Figure 1. Dumpsite in Sisimiut (left) and Polyethylene waste fishing nets (right)

2.2 Mechanical properties of HDPE fibres

Uniaxial tensile strength, Young's modulus and elongation strain of monofilament HDPE fibres were determined in accordance with ASTM standards [22]. The test was conducted on randomly chosen unconditioned new fibres and waste fibres.

A monofilament fibre with a total length of app. 150 mm was mounted at the centre of a thick paper with a hollow section of 20 mm, 25 mm or 30 mm, respectively, which corresponded to the gage length. According to ASTM standards [22] at least three different gage lengths has to be tested in order to determine Young's modulus. Test setup is shown in Figure 2.

The fibre was anchored on thick paper with WEICON PP-PE 2-component glue. Tensile load was applied in a displacement controlled Instron 6022 machine with a constant displacement rate of 20 mm/min in order to obtain failure within 30 s. A successful failure was one on the free length of the fibre. As a consequence of the smooth fibre surface, it was a challenge to fix the fibre near the gripping system, and around 30 % of the failures were categorized as unsuccessful due to failure too close to the gripping system. At least eight successful tests were carried out for each gauge length.
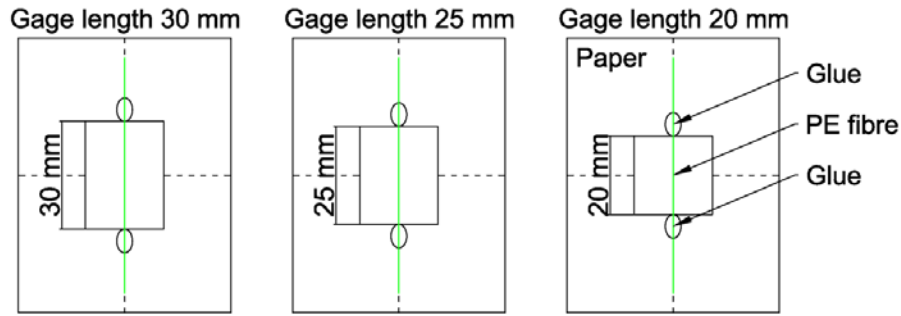
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Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

Figure 2. Test-setup for tensile testing of monofilament fibres

In order to determine Young's modulus, E, the elongation over the force $\Delta L/F$ was plotted against l_0/A. This gives the following formula, where C_s is the system compliance.

$$\frac{\Delta L}{F} = \frac{\Delta l}{F} + C_s = \frac{l_0}{E \cdot A} + C_s .$$

The cross-section area used in the calculation was for all fibres based on a mean value of the equivalent diameter, d = 0.3 mm.

3   Results

3.1 Physical properties of HDPE fibres

The density of HDPE fibres were measured to 0.95 g/cm^3. SEM images of a piece of a new fibre and waste fibre are shown in Figure 3. The general tendency was that the new fibres have a more equal and smooth surface with fewer loose parts than the waste fibre.
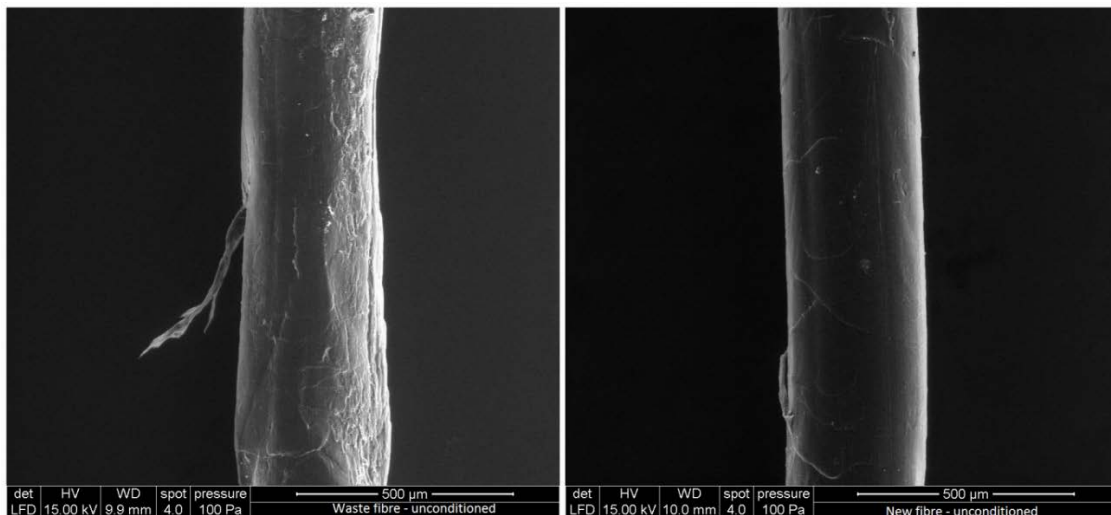

Figure 3. SEM images (300x) of waste fibre (left) and new fibre (right) of polyethylene

International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

3.2 Mechanical properties of polyethylene fibres

The mechanical properties obtained by tensile testing are shown in Table 1 and 2, and stress-strain relationship is illustrated for unconditioned fibres in Figure 4. The tensile strength for new and waste fibres ranged between 403-445 MPa and 312-370 MPa, respectively. The peak strains for both new and waste fibres varied between 26-33 %. The new fibres obtained tensile strengths which were about 20 % higher than for the waste fibres, whereas the elongation strain for both new and waste fibres were very similar.

A large standard deviation was observed for all samples, though it is overall highest for the waste fibres. This was expected due to differences in equivalent diameter, load impact history and degree of deterioration. From the manufactures view, the properties of each fishing line, which consists of about 40 fibres, are of importance rather than the properties of each single fibre.

Table 1. Mechanical properties of unconditioned waste fibres. Values in parentheses are standard dev.

Waste fibre - Unconditioned						
Length	Peak strength	Tensile strength	Peak elongation	Peak strain	$\Delta L/F_t$	l_0/A
l_0 [mm]	F_{max} [N]	σ_t [MPa]	Δl [mm]	ε_t [%]	[mm/N]	[1/mm]
20	26.2 (5.0)	370.8 (70.1)	6.7 (1.2)	33.3 (5.9)	0.26	0.14
25	25.1 (1.8)	355.0 (25.6)	6.7 (0.8)	26.7 (3.3)	0.27	0.18
30	22.1 (4.8)	311.9 (67.8)	8.1 (1.4)	27.1 (4.7)	0.37	0.21
Mean	**24.5**	**345.9**	**7.2**	**29.0**		

Table 2. Mechanical properties of unconditioned new fibres. Values in parentheses are standard dev.

New fibre - Unconditioned						
Length	Peak strength	Tensile strength	Peak elongation	Peak strain	$\Delta L/F_t$	l_0/A
l_0 [mm]	F_{max} [N]	σ_t [MPa]	Δl [mm]	ε_t [%]	[mm/N]	[1/mm]
20	29.4 (1.9)	415.4 (26.5)	6.1 (0.6)	30.6 (2.8)	0.21	0.14
25	31.2 (3.0)	441.7 (41.8)	6.8 (1.2)	27.2 (4.8)	0.22	0.18
30	28.5 (3.4)	403.7 (47.8)	8.5 (1.9)	28.5 (6.3)	0.30	0.21
Mean	**29.7**	**420.2**	**7.2**	**28.8**		

International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark
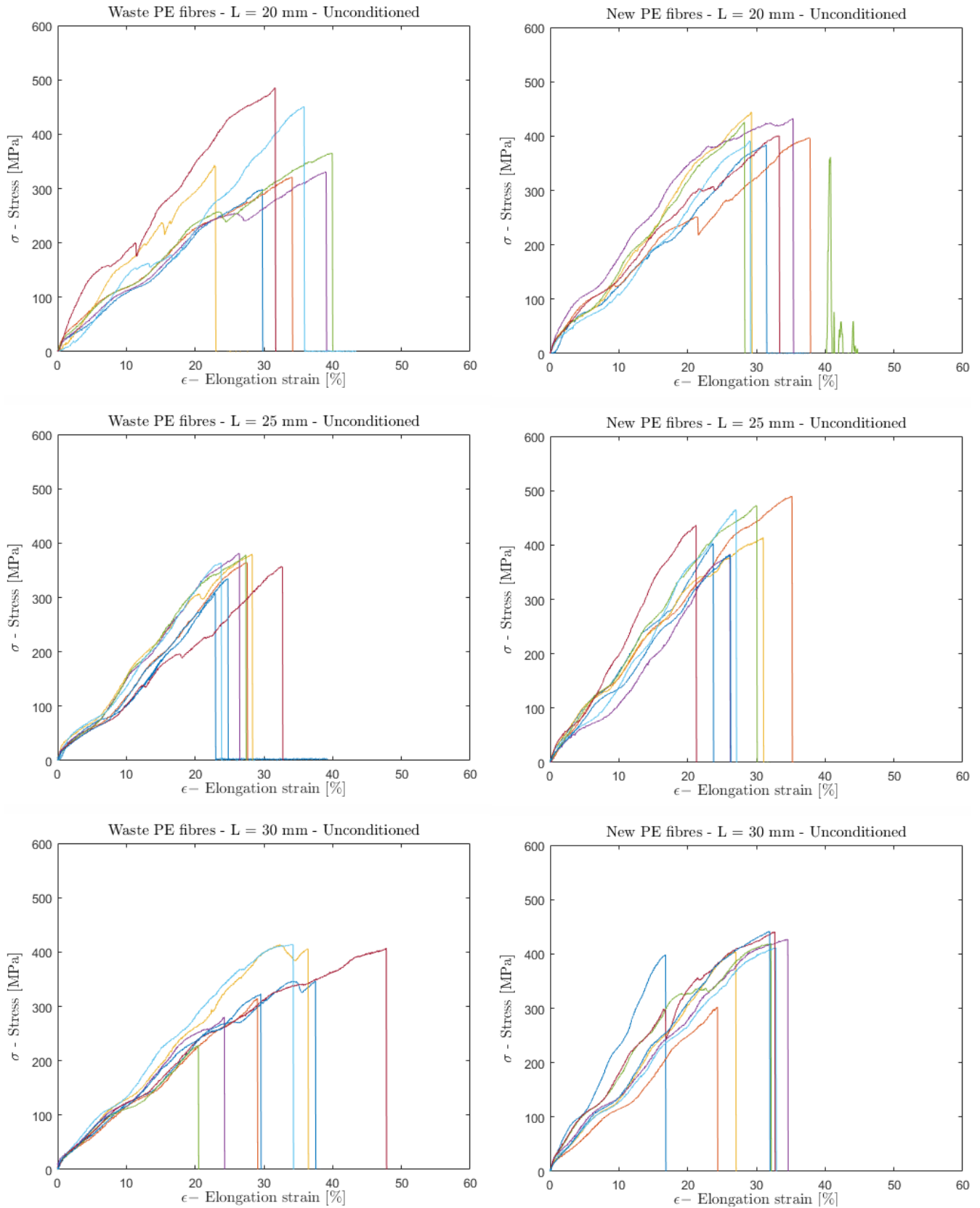
Figure 4. Stress-strain plot of unconditioned waste fibres (left) and new fibres (right)

International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

Young's modulus was calculated as the slope of the best fitting line in Figure 5. The results for unconditioned fibres are shown in Table 3 and are ranging between 1000-1040 MPa. Due to a great standard deviation in the fibre strength-strain relationship and thereby a low R^2-value of 0.6-0.7, it resulted in an unreliable outcome of Young's modulus. However, the large strain and the slope of the stress-strain curves show that the stiffness is low if the fibres are considered as linear elastic.
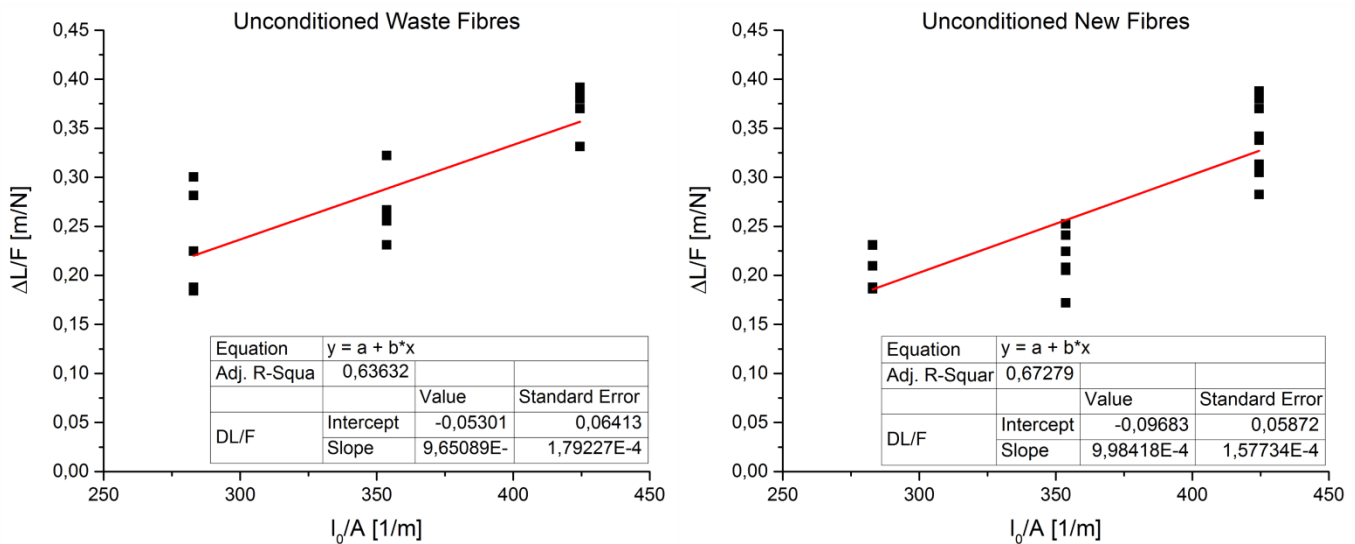

Figure 5. ΔL/F vs. L_0/A plots to determine E-modulus of waste (left) and new (right) fibres

Table 3. E-modulus of monofilament fibres

Unconditioned:	New fibres	Waste fibres
Slope of line	9,984E-4	9,651E-4
E-modulus	1002	1036

4   Discussion

Since the aim of this paper is to determine the applicability of using waste fishing nets as fibre reinforcement in cementitious building materials, the properties are compared to other fibres of polyethylene and of polypropylene found in the literature [11], [16], [23]. Properties such as diameter, specific density, tensile strength, Young's modulus and ultimate elongation strain are compared with other fibres in Table 4.

Specific density and tensile strength correspond well to other fibres shown in Table 4, whereas Young's modulus is significantly lower. The low modulus results in a lower stiffness, which will allow greater deformation before failure. Even though Young's modulus for the nets is located in the lower range, all fibre types shown in Table 4 are categorised as "low-modulus fibres", which, when used as reinforcement, are unlikely to give strength improvement, but to help with absorbing large amounts of energy resulting in greater degree of toughness and to improve the shrinkage cracking in young concrete.

International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

Regarding the physical properties of the fibres, the fibre surface is relatively smooth, which can lead to a deficient bonding between fibres and concrete matrix. As for the diameter, Banthia [16] stated that fibres are categorized in two groups; micro- and macro-fibres, whereas micro fibres have an equivalent diameter less than 0.3 mm, and macro fibres a diameter greater than 0.3 mm [16]. The investigated polyethylene fibres had a diameter of 0.27-0.33 mm, why they are just in the border area between the two categories.

Table 4. Properties of polyethylene fibres from fishing net [21], compared with fibres used for concrete reinforcement. *Experimentally determined.

Reference	Fibre Diameter [µm]	Specific Density [g/cm^3]	Tensile Strength [MPa]	Young's Modulus [MPa]	Ultimate Strain [%]
PE fishing net	270 - 330*	0.95*	310 - 445*	1000*	26 – 34*
Polyethylene (PE) fibres used as reinforcement of cementitious materials					
ACI [11]	25 - 1000	0.92 - 0.96	75 - 590	5000	3.0 - 80
Banthia [16]	40	No data	400	2000 - 4000	100 - 400
Kobayashi [23]	900	0.96	200	5000	No data
Polypropylene (PP) fibres used as reinforcement of cementitious materials					
ACI [11]	No data	0.90 - 0.91	135 - 700	3500 - 4800	15
Banthia [16]	10 – 150	No data	200 - 700	500 - 9800	10 - 15
Sun [14]	100	0.91	560-770	3500	16-22

For future work, the alkali-resistance of the fibres will be investigated and mortar/concrete samples reinforced with waste PE fibres will be investigated.

5   Conclusion

Investigation of the mechanical properties of waste fibres and new fibres from fishing nets of high density polyethylene indicated that:
- The surface of the fibres is smooth, which might lead to poor bonding between fibres and the cementitious matrix.
- The tensile strength of waste fibres was reduced with 20 % compared to new fibres, but the ultimate elongation strain and Young's modulus was more or less unchanged.
- Young's modulus was low compared to other fibres used as reinforcement in cementitious materials, whereas the tensile strength corresponds well to other fibres.

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International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
22-24 August 2016, Technical University of Denmark, Lyngby, Denmark

6   Acknowledgement

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International RILEM Conference on Materials, Systems and Structures in Civil Engineering
Conference segment on Cold Region Engineering
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Circular Ocean is funded under the European Regional Development Fund (ERDF) Interreg VB Northern Periphery and Arctic (NPA) Programme

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