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REUSE OF POLYETHYLENE FIBRES FROM DISCARDED FISHING NETS AS REINFORCEMENT IN GYPSYM-BASED MATERIALS

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Abstract

In this study, the potential of reusing plastic fibres from discarded waste fishing nets of polyethylene (PE) as fibre reinforcement in gypsum-based building materials is investigated. The fishing nets were not reprocessed, but simply washed and cut to monofilament fibres by an industrial operation. The fibre length was ranging from 1 mm (pulp) to 65 mm, and the diameter from 0.25 mm to 0.35 mm. Gypsum-based prisms and cylinders were cast with these fibres (fibre addition of 0.5 – 2.00 wt%). Mechanical properties such as compressive strength and three-point bending strength of fibre reinforced cylinders and prisms were determined by laboratory-scale testing. A decrease in first-crack strength of the prisms was observed. However, the addition of waste PE fibres resulted in improved post-crack behaviour.

Keywords:

Plastic waste; Reuse of fishing nets; Fibre reinforced gypsum; Mechanical properties

1 INTRODUCTION

Lost or otherwise discarded fishing nets made of non-biodegradable polymeric material is an increasing concern for the marine environment (Macfadyen, Huntington, & Cappell, 2009). To prevent these so-called "ghost-nets", it is considered essential to find new applications for discarded waste nets. This work is about the potential of reusing polyethylene (PE) fibres mechanically processed from discarded waste fishing nets as reinforcement in traditional gypsum-based building materials.

Gypsum-based building materials have been widely used in the building construction industry (Hagemann, 1977). However, considering the mechanical properties, the material is generally associated with a brittle behaviour when exposed to tension (Dalmay et al., 2010). Therefore, it is often reinforced with fibres of different materials to increase the post-crack performance and toughness (Flores Medina & Barbero-Barrera, 2017; Hernández-Olivares, Oteiza, & de Villanueva, 1992). Different fibre materials used as reinforcement of gypsum-based building materials have been studied in the literature and include fibres of glass (Martias, Joliff, & Favotto, 2014), polyamide (PA) (Eve et al., 2002; Vasconcelos, Lourenço, Camões, Martins, & Cunha, 2015), polypropylene (PP) (Deng & Furuno, 2001; Flores Medina & Barbero-Barrera, 2017; Gencel et al., 2014), and natural fibres such as sisal (Hernández-Olivares et al., 1992), hemp, flax (Dalmay et al., 2010), cellulose (Araújo Carvalho, Calil, & Savastano, 2008), and abaca (Iucolano, Caputo, Leboffe, & Liguori, 2015).

Incorporation of waste materials as fibre reinforcement in building materials, such as gypsum-based (Araújo Carvalho et al., 2008; Ramos & Mendes, 2014; Serna, Río, Palomo, & González, 2012; Vasconcelos et al., 2015) and especially cement-based (Sharma & Bansal, 2016) materials, has been studied with the aim of revealing ways to produce more sustainable building materials. The benefits of using fibres from discarded fishing nets as reinforcement of building materials include the fact that a waste material is being reused and that only a low amount of energy is necessary for processing the fibres. The PE fish nets used in this study consisted of either braided or twisted monofilament fibres, which are relatively easy to separate and process to fibres applicable for fibre reinforcement of construction materials.

The aim of this study is to investigate the effect of adding fibre reinforcement from discarded PE fishing nets to gypsum-based specimen. The influence of addition of fibres on compressive strength, first crack strength, and post-crack behaviour of the material is examined.

2 MATERIALS AND METHODS

The materials used in this study include hemihydrated natural gypsum for production of gypsum-based specimen and PE fibres from discarded waste fishing nets.

2.1 Fibres

The monofilament waste fibres used as fibre reinforcement were provided by Plastix A/S in Denmark (Plastix A/S: http://plastixglobal.com/), which

is a company collecting and reprocessing waste fishing nets. Prior to the reprocessing, the fish nets were separated into different materials fractions. After the separation, the nets were mechanically being cut to smaller fibres. A sample of the monofilament fibres are shown in *Fig. 68*.

Fig. 68. Monofilament fibres of polyethylene by Plastix A/S produced by mechanical cutting operation

The fibres are made of PE originating from fishing nets with different properties, why differences in length, diameter, density, and mechanical properties are present. PE has a hydrophobic nature and does not absorb water. The properties of the waste PE fibres used in this study are shown in Tab. 41. Further, the length is varying between 1-65 mm due to the "uncontrolled" cutting process. A histogram of the fibre lengths is shown in Fig. 2. The mean length is 14 mm and the fibres have a straight shape.

Tab. 41. Properties of waste fibres of PE (I. M. G. Bertelsen & Ottosen, 2016; I. Bertelsen & Ottosen, n.d.)

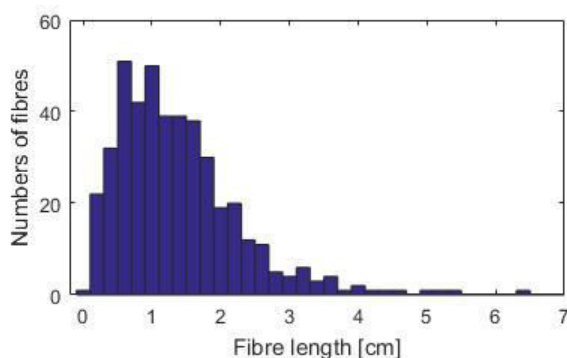|	Density	Length	Diameter	Strength	Stiffness
	ρ [g/cm^3]	L [mm]	d [mm]	σ_t [GPa]	E [GPa]
PE	~0.95	1-65	0.27-0.33	0.26-0.35	0.8-1.9

Fig. 69. Fibre length distribution

Preparation of fibres

The PE fibres were cleaned in tap water to remove residues such as sand, salt and other impurities. The cleaning process had the following steps:

- Adding app. 1.5 L of fibres and app. 5 L of tap water to a bucket and stirring it by hand for app. 5 min.
- The fibres (with a density below water) were left to rest for another 5 min. before they were removed from the surface and added to a clean bucket.

- The same amount of water was added-, stirred for 5 min. and left to rest overnight.
- The first two steps were repeated the following day, whereupon the fibres were spread out on a table to dry for at least 24 h.

2.2 Gypsum

Hemihydrated natural gypsum ($CaSO_4$ + ½H_2O) of the type "Miller Modelgips" supplied by C. Flauenskjold was used to cast the specimen for mechanical testing. The density of the material ranges from 2.31-2.97 g/cm^3. Prismatic specimen with dimensions of 40 x 40 x 160 mm and cylinders with diameter and height of 60 x 120 mm were prepared. Each batch consisted of three test specimens with the following mix design: 700 ± 1 g of tap water, 1600 ± 2 g of hemihydrated natural gypsum and varying fibre content.

The specimen preparation included the following steps:

- Dry-mixing of hemihydrated gypsum and PE fibres in a metal bowl to uniformly distribute the fibres.
- Hydrating the mixture by adding all water under mechanical shaking in a Hobart machine for 15 s.
- The specimens were casted in either steel or plastic moulds and vibrated to ensure complete filling of the moulds and to remove air bubbles. The moulds were subsequently covered with a metal plate with metal weights on top to prevent non-uniform expansion.
- Specimens were demoulded after 24 hours and dry cured for 48 hours at room temperature until testing.

One unreinforced control batch and five fibre reinforced batches fibre contents varying from 0.50 wt% to 2.00 wt%, with steps of 0.50 or 0.25 wt% were prepared.

The mixing and casting procedure is shown in *Fig. 70*.

Fig. 70. Mixing and casting of prisms and cylinders

2.3 Compression test on cylinders

The compressive strength of cylinders with varying fibre contents was tested in a TONI Industries compression machine. A force-controlled load was applied in a rate of 0.5 kN/sec. The compressive strength is calculated as (DS/EN-196-1-1, 2005)

$$R_c = \frac{F_c}{A}$$

where F_c is the maximum load at fracture and A the cross section area of the cylinders.

2.4 Three-point bending test on prisms

Three-point bending tests of the prismatic specimens were performed in accordance with DS/EN 196-1-1 (DS/EN-196-1-1, 2005). The clear span was 100 mm and the test setup is shown in Fig. 4.

The test was performed in a hydraulic displacement controlled testing machine, Instron 6022. A load was applied in a rate of 1 mm/min.
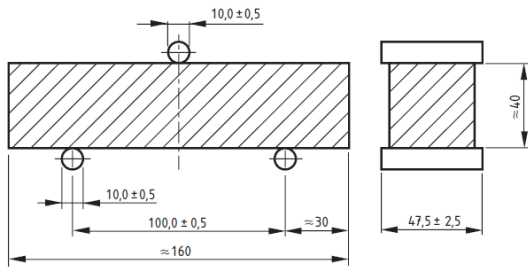
Fig. 71. Setup for three-point bending test (DS/EN-196-1-1, 2005)

The theoretical working curve for the three-point bending test is shown in *Fig. 72*. The point where the first crack appears is denoted as point A, (the critical load, P_{cr}; midspan deflection, δ_{cr}), and corresponds to the strength of the matrix. The first crack strength, f_{cr}, is calculated as follows (DS/EN-196-1-1, 2005)

$$f_{cr} = \frac{3 \cdot P_{cr} \cdot l}{2 \cdot a^3}$$

Where *l = 100* mm is the length of the clear span, and *a = 40* mm is the side of the square section of the prism.

The maximum post-crack load, P_B, is shown as point B, and is the strength of the composite material.
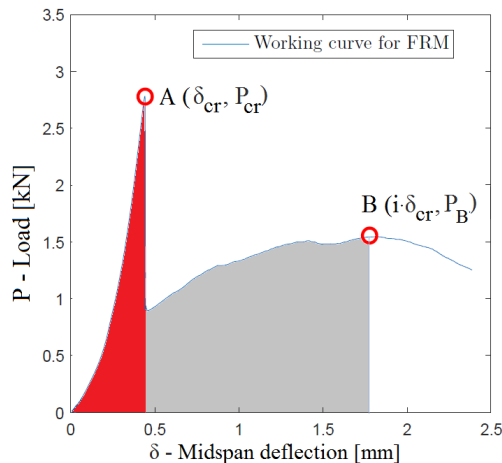

Fig. 72. Theoretical working curve for a fibre reinforced material (FRM) from a three-point bending test

3 RESULTS AND DISCUSSION

3.1 Compressive strength of cylinders

The compressive strength, R_c, of cylinders is shown in *Tab. 42*. Despite the fact that the unreinforced control cylinder obtained the highest compressive strength, there is no clear correlation between compressive strength and fibre content.

Tab. 42. Results from compressive test and three-point bending test. Mean values from three tests are given

	Rc	Pcr	δcr	fcr	PB,max
	[MPa]	[kN]	[mm]	[MPa]	[kN]
Control	10.78	1.57	0.43	3.69	0
0.5 wt%	10.02	1.41	0.41	3.29	0.18
1.0 wt%	10.34	1.39	0.41	3.25	0.36
1.5 wt%	9.58	1.39	0.39	3.26	0.45
1.75 wt%	10.51	1.34	0.44	3.15	0.54
2.0 wt%	10.27	1.34	0.38	3.15	0.68

3.2 Bending strength of prisms

The results from the three-point bending test of gypsum prisms are shown in Fig. 6. The figure shows an unreinforced control specimen (a) and fibre reinforced specimens with fibre content 0.5, 1.0, 1.5, 1.75 and 2.0 wt% (b-f). Tab. 2 shows the mean values of strength parameters obtained from the three-point bending test from three specimens.
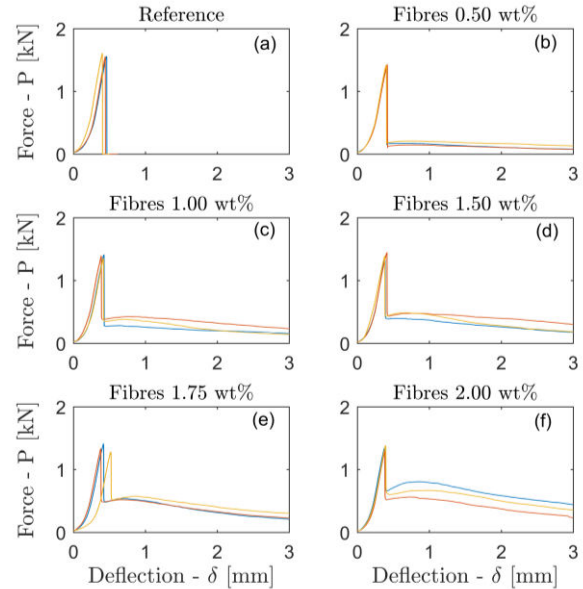

Fig. 73. Load-deflection curves for gypsum prisms. (a) control specimen, (b) fibre content 0.5 wt%, (c) fibre content 1.0 wt%, (d) fibre content 1.5 wt%, (e) fibre content 1.75 wt%, (f) fibre content 2.0 wt%

The peak strength, f_{cr}, at which the first crack occurs, is decreasing with increasing fibre content. The control specimen cracked at a load of 1.57 kN corresponding to a flexural strength of 3.69 MPa, whereas the specimen with 2.0 wt% of fibres cracked at 1.34 kN corresponding to a flexural strength of 3.15 MPa.

After the first crack appears in point A, the brittle gypsum-based material matrix loses its tensile strength, and the curve is dropping noticeably until the fibres start working. The large drop is a result of low fibre stiffness and poor bonding strength between fibres and material matrix. However, the maximum post-crack load, $P_{B,max}$, is increasing from 0.18 kN for a fibre content of 0.5 wt% and up to 0.68 kN for a fibre content of 2.00 wt%.

The maximum post-crack load, P_B, is increasing up to 0.68 kN with a fibre content of 2.0 wt%.

4 CONCLUSION

This study was done as an initial examination of the potential of using polyethylene fibres mechanically cut from discarded waste fishing nets as reinforcement in gypsum-based building materials. The addition of fibre reinforcement is mainly done to improve the mechanical properties of gypsum-based specimen, which otherwise has a brittle failure. Mechanical properties were determined from compression tests and three-point bending tests. Different fibre contents of 0.5, 1.0, 1.5, 1.75 and 2.0 wt% were examined.

The following tendencies were observed:

- A fibre content of 2.00 wt% was the maximum quantity of fibres possible to mix properly into the gypsum matrix.
- The first-crack load, $P_{cr,}$ was decreasing with increasing fibre content.
- The post-crack behaviour was increasing with increasing fibre content. However, the post-crack strength was very low compared to the first-crack strength, P_{cr}.

5 ACKNOWLEDGEMENT

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