Valorization of Discarded Fishing Gear Fibers in Cementitious Composites: A Sustainable Approach.

Ali HUSSAN[1], Nassim SEBAIBI[1]

[1] *Builders Lab, Builders Ecole d'ingénieurs, COMUE Normandie Université, 1 Rue Pierre et Marie Curie, 14610 Epron, France*

RESUME Within cementitious composites (CC), this study investigates the valorization of polyethylene (PE) fibers derived from discarded fishing trawls and polypropylene (PP) fibers sourced from discarded fishing ropes. Sustainable processing methodologies are employed. Utilizing natural elements such as wind and rain, an environmentally responsible cleansing method effectively eliminates contaminants from the fibers. Additionally, an innovative mechanical cutting process that employs a cutting mill guarantees efficient fiber cutting. The durability of these fibers in alkaline environments was validated through resistance assessments in NaOH solutions, showing minimal deterioration. The impact of fiber length (FL) and fiber volume fraction (FVF) on the mechanical properties of CC was thoroughly examined. The findings suggest that the mechanical performance of CC improved with the increase in FL while keeping the FVF to 0.7% for both PE and PP fibers. Exceeding the FVF above 0.7% leads to a decline in the mechanical performances of CC, which is attributed to the increase in porosity with fiber addition. When comparing PE and PP fibers, it is noted that PE fibers show better workability, bolstered flexural strengths, and facilitated better control over porosity as compared to PP fibers. This study is a part of project VALNET, which presents a scalable and effective method for transforming marine plastic waste into construction materials, in harmony with circular economy concepts and advocating for sustainable options for fiber reinforcement in cement-based composites.

Mots-clefs Discarded fishing gear; polypropylene and polyethylene fibers; Sustainable solution; reinforced cementitious composites; Alkaline durability.

1. INTRODUCTION

Marine plastic litter, especially discarded fishing gear, poses a persistent threat to ocean ecosystems and coastal economies [1-6]. In 2016, more than 11 million tons of plastic waste entered the world's oceans, and projections indicate a rise to 29 million tons annually by 2040 if no measures are taken to tackle the problem [7]. Discarded fishing trawls, largely made from high-density polyethylene, along with ropes predominantly crafted from polypropylene, constitute a significant segment of this waste category. They continue to ensnare marine life and contribute to environmental harm long after their usefulness has ended. Amid this environmental crisis, the construction sector is under considerable pressure to lower carbon emissions, as the production of Portland cement accounts for around 8% of global human-induced CO_2 emissions [8,9]. The integration of recycled fiber into cementitious composites (CC) offers a notable benefit by effectively diverting plastic from marine environments while also reducing the reliance on energy-demanding virgin reinforcement materials i.e., virgin polypropylene fibers [10-14].

Prior laboratory investigations have shown that fiber recovered from discarded fishing gear can effectively fill micro-cracks [15, 16], improve post-cracking toughness [17, 18], are crucial in improving flexural strength [19, 20], tensile strength [17, 21] and durability [22, 23] of cementitious composites. However, widespread implementation is obstructed by (i) labor-intensive manual cutting and cleaning processes and (ii) variability in fiber quality. Project VALNET tackles these challenges by combining an eco-friendly cleaning process with an efficient cutting-mill technique that produces well-graded PE and PP fibers ideal for industrial mortar manufacturing. This article explores the VALNET findings, following the path from discarded fishing gear to performance-enhanced fiber-reinforced mortars. Attention is concentrated on two design parameters—fiber length (FL) and fiber volume fraction (FVF)—as well as a comparison of PE and PP in both their fresh and hardened state properties. The objectives of the study are as follows:

- Establish the procedure for cleaning and cutting PE and PE to convert them into fibers suitable for industrial use.
- Examine the physical and mechanical characteristics of PE and PP fibers prior to their integration into the mortar.
- Assess the durability of PE and PP fibers when exposed to highly alkaline environments.
- Analyze how each fiber type influences the mechanical characteristics of the mortar.
- Assess how the size and proportion of fibers influence the properties of mortar in both its fresh and hardened forms.

2. MATERIALS AND METHODS

2.1. Raw Materials

Cement and aggregates. A low-clinker CEM V/A 32.5 N Portland-slag-fly-ash cement supplied locally was blended with 0/4 mm crushed quarry sand.

Fishing-gear fibers. Discarded trawl (PE) and rope (PP) were obtained from Synergie Mer & Littoral in Normandy, France as in Figure 1.

The density of all fibers was assessed using NF EN ISO 18753, 2017, while their tensile strength (TS) and Young's modulus (YM) were evaluated in accordance with ASTM C1557-03, 2013. The average length and average diameter were measured through granulometry analysis conducted using ImageJ software. The results are presented in Table 1.

TABLE 1. Physical and mechanical properties of polyethylene (PE), and polypropylene (PP) fibers.

Properties	PE	PP
Density (g/cm3)	1.09	0.94
Tensile strength (MPa)	203	148
Young's modulus (GPa)	3.20	1.89
Average length (mm)*	3.67, 8.67, 9.81, 15.81, 19.70	3.81, 7.22, 10.44, 14.98, 20.57

Average diameter (mm)	150	130

*Average fiber lengths obtained utilizing 4mm, 8mm, 10mm, and 20mm sieves, as well as without any sieve at the outlet of the cutting mill. It is crucial to recognize that the average length derived from these sieves does not exactly match the dimensions of the sieve. The fibers collected exhibit a range of lengths, with the average length detailed in Table 1. For additional information, refer to [14].

FIGURE 1. Visuals of a discarded fishing trawl (left) and a discarded fishing rope (right).

2.2. Fiber Cleaning and Cutting

Natural cleaning. Bundles of discarded fishing trawl and rope were placed on steel racks outdoors from August 2023 to January 2024, subjected to approximately 600 mm of cumulative rainfall and prevailing winds averaging 4.5 m. s-1. The salinity of runoff was observed every two weeks; chloride concentrations decreased to below 0.3 ppt after 20 weeks, achieving the goal for integration into cementitious matrices.

Mechanical cutting. A Retsch SM300 cutting mill (3 kW, 100–3000 rpm) featuring interchangeable bottom sieves (4, 8, 10, 20 mm, plus "open" mode or without sieve "WO") generated five different lengths of fibers with average lengths of 3.67, 8.67, 9.81, 15.81, 19.70 mm for PE and 3.81, 7.22, 10.44, 14.98, 20.57 mm for PP, respectively.

Figure 2-a illustrates the discarded fishing rope prior to entering the cutting mill, Figure 2-b depicts the cutting process of the discarded fishing rope, Figure 2-c presents visuals of the discarded fishing trawl before it is fed into the cutting mill, and Figure 2-d showcases the cutting process of the discarded fishing trawl. Figure 2-m displays the PP fibers of varying lengths obtained from discarded fishing rope and Figure 2-n represents the PE fibers obtained from discarded fishing trawl. Please note that WO indicates the fiber obtained without the application of any sieve at the outlet of the cutting mill.

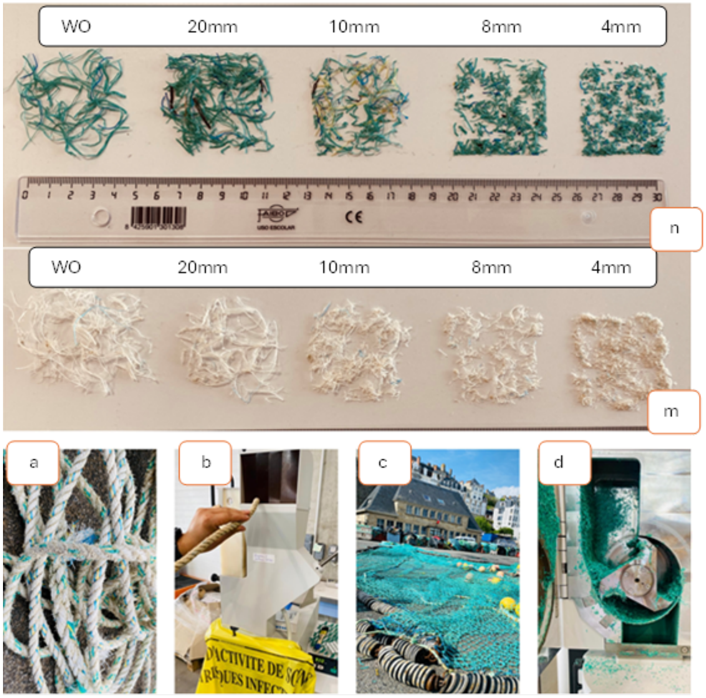

FIGURE 2. The methods of cutting and the final outcomes of polyethylene and polypropylene fibers.

2.3. Mortar mix design

A reference control mortar was utilized with a water-to-cement ratio of 0.45, a sand-to-cement ratio of 1.5 by mass, and 0.001% polycarboxylate superplasticizer based on the weight of cement. Mortars reinforced with fibers were developed by substituting PE or PP fibers at three distinct fiber volume fractions: 0.3, 0.7, and 1.0 % (calculated based on the total composite volume). The mortar formulations, designated as MC contains no fibers is a reference formulation, and this reference formulation was compared against formulations MPE2, MPE4, MPE8, MPE10, MPE20, and MPE-WO (incorporating PE fibers sourced from 2mm, 4mm, 8mm, 10mm, 20mm sieves and without sieve respectively), along with MPP2, MPP4, MPP8, MPP10, MPP20, and MPP-WO (featuring PP fibers derived from 2mm, 4mm, 8mm, 10mm, 20mm sieves and without sieve respectively). Table 2 gives the details of each formulation studied in the study.

TABLE 2. Mortar formulations using different fiber length (FL) and fiber volume fraction (FVF).

Cement	**Sand**	**Water**	**Superplasticizer**	**Fibers**			**Mortar Reference**	
				FVF (%)	**Average FL (mm)**			
1	1.5	0.45	0.001	0	0		MC	
					PE	**PP**	**PE**	**PP**
				0.3, 0.7 or 1	3.67	3.81	MPE4	MPP4
				0.3, 0.7 or 1	8.67	7.22	MPE8	MPP8
				0.3, 0.7 or 1	9.81	10.44	MPE10	MPP10
				0.3, 0.7 or 1	15.81	14.98	MPE20	MPP20
				0.3, 0.7 or 1	19.70	20.57	MPE-WO	MPP-WO

2.4. Mechanical testing programme

Fresh state: Determination of mortar workability using flow-table diameter (NF EN 1015-3).

Hardened state:

- Water-accessible porosity (WAP) via vacuum saturation (NF P18-459).
- Compressive strength (f^c) on 40 mm cubes and flexural strength (f^f) on 40 × 40 × 160 mm prisms at 28 days curing in water at room temperature (NF EN 196-1).

3. RESULTS AND DISCUSSION

3.1. Fiber durability and surface integrity

Microscopy performed before and after exposing PE and PP to 10% NaOH for 24 hours at room temperature revealed negligible pitting or fibrillation; the alkaline impact was limited to the elimination of surface wax (Figure 3). The tensile retention capability surpassing 95% indicates that PE and PP are highly compatible with high-pH cement matrices as reported in multiple previous studies [15, 17, 24, 25]. The results are tabulated in table 3.

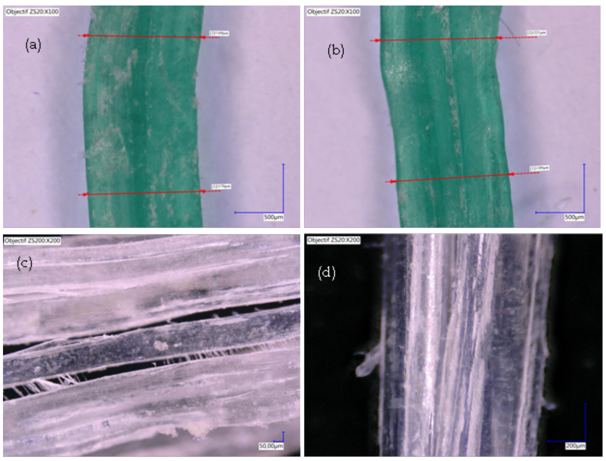

FIGURE 3. Microscopy results of fiber surface conditions: (a) PE fibers before treatment; (b) PE fibers after treatment; (c) PP fibers before treatment; (d) PP fibers after treatment [13].

TABLE 3. Durability of polyethylene and polypropylene fibers against the alkaline environment [13].

Fibers	Conditions before treatment		Conditions after treatment		Results	
	TS (MPa)	Mass (g)	TS (MPa)	Mass (g)	The ratio of TS after and before treatment (%)	Mass loss (%)
PE	203	10	198	9.94	97.54	0.6
PP	148	10	141	9.91	95.27	0.9

3.2. Fresh-mix workability

Earlier investigations [26-29] have demonstrated a reduction in the workability of mortar when fibers (PE or PE) are included. Our analysis validates and reinforces this identified pattern. The findings suggest that the FL plays a minor role in the workability of mortars, while the FVF has a more significant influence. This relationship could clarify the limited effect of FL on the workability of mortars. Nonetheless, a slight reduction in workability was observed as the FL increased. An increase in the FVF leads to a reduction in workability, while the inclusion of 1% fiber shows the least amount of workability. In the comparison between PE and PP, it is observed that the addition of PP fibers leads to a more significant reduction in workability than that of PE fibers (Figure 4). The elevated water absorption coefficient of PP fibers could explain the comparatively greater reduction in workability.

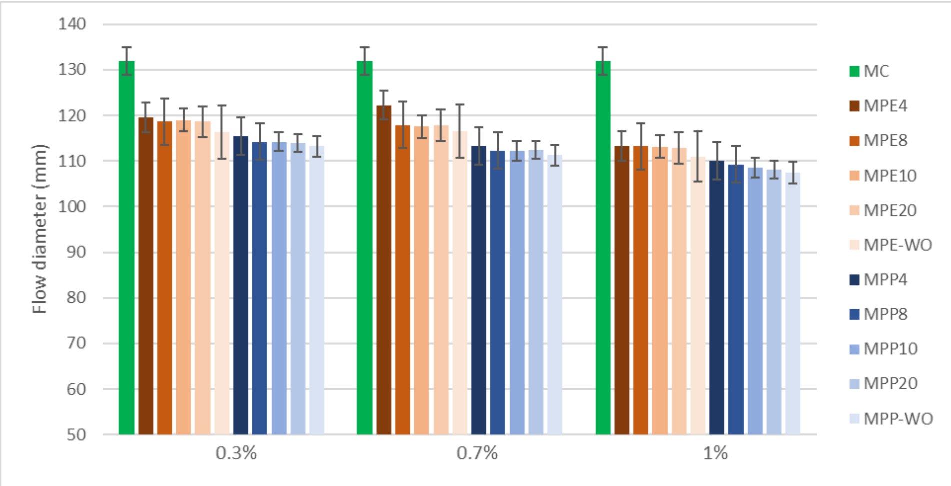

FIGURE 4. Influence of fiber different fiber length (FL) and fiber volume fraction (FVF) on flow-table dispersion.

3.3. Water-accessible porosity (WAP) evolution

Keeping the FVF constant at 0.7%, the influence of FL on WAP is analyzed at 28 days and 90 days of curing time, considering the effects of two different fiber types: PE and PP. Figure 5 provides a visual representation of this information.

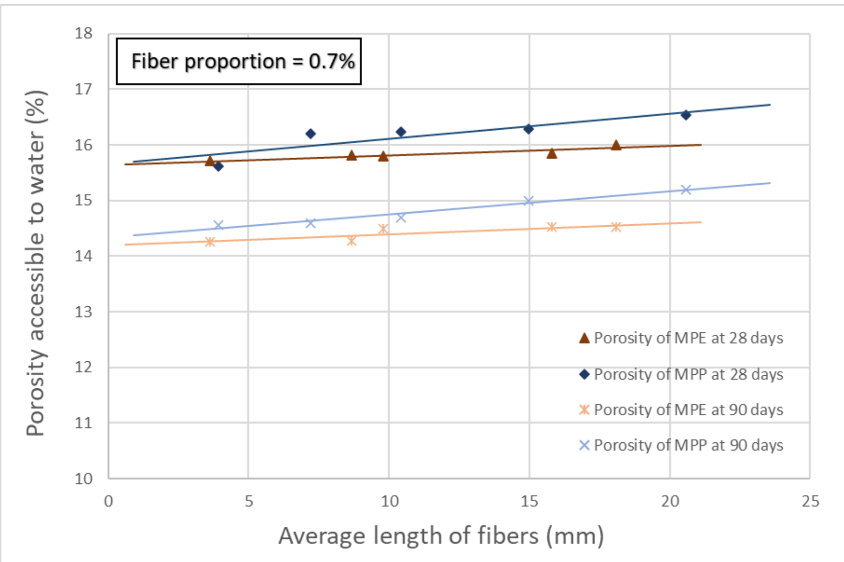

FIGURE 5. The effects of fiber length (FL) on water-accessible porosity (WAP) of mortar.

The investigation initially centered on the influence of FL on WAP. The findings indicate a noticeable rise in WAP corresponding with an increase in FL. Mortar made with PP fiber (MPP) shows increased WAP values at the constant FL after curing for 28 days and 90 days in comparison to Mortar made incorporating PP fibers (MPE). A reduction in porosity was noted at 90 days in comparison to 28 days.

The next aim is to assess the impact of FVF on mortar porosity, keeping the fiber length constant (MPE/PP-WO). WAP is measured at 14% with zero FVF, rising to 17.23% at 1% FVF for MPE-WO and reaching 17.80% for MPP-WO following a 28-day curing period (Figure 6). Several investigations have already recorded a rise in the porosity of cementitious materials with the addition of fibers [29-31].

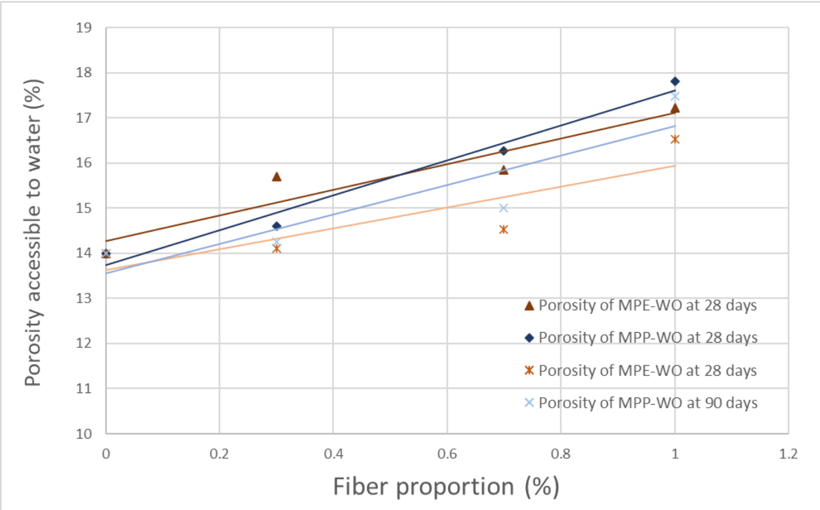

FIGURE 6. The effects of fiber volume fraction (FVF) on water-accessible porosity (WAP) of mortar.

3.4. Compressive and flexural strength test

Results of compressive strength (CS) and flexural strength (FS) are presented in Figure 7 and 8.

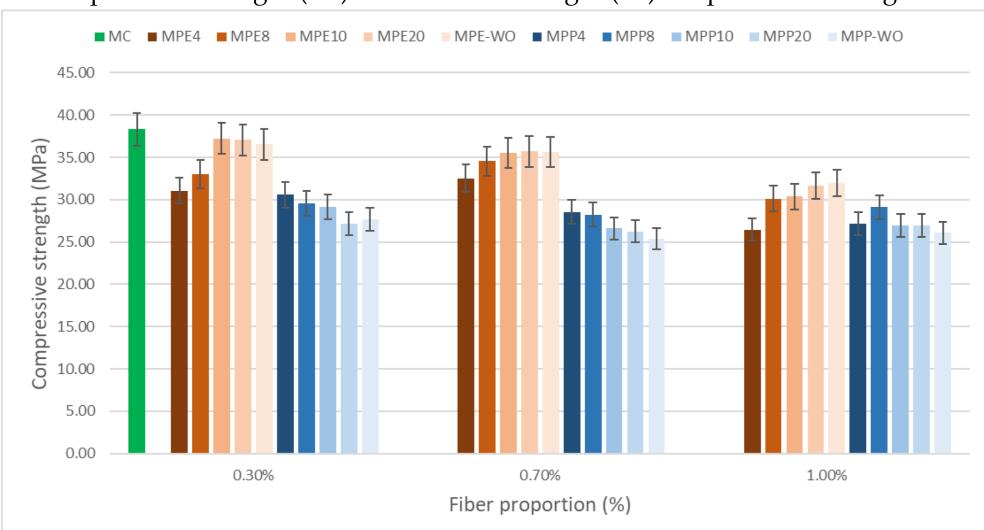

FIGURE 7. Results of the compressive strength test after 28 days of water curing for the controlled mortar, and the mortar with PE fibers and PP fibers.

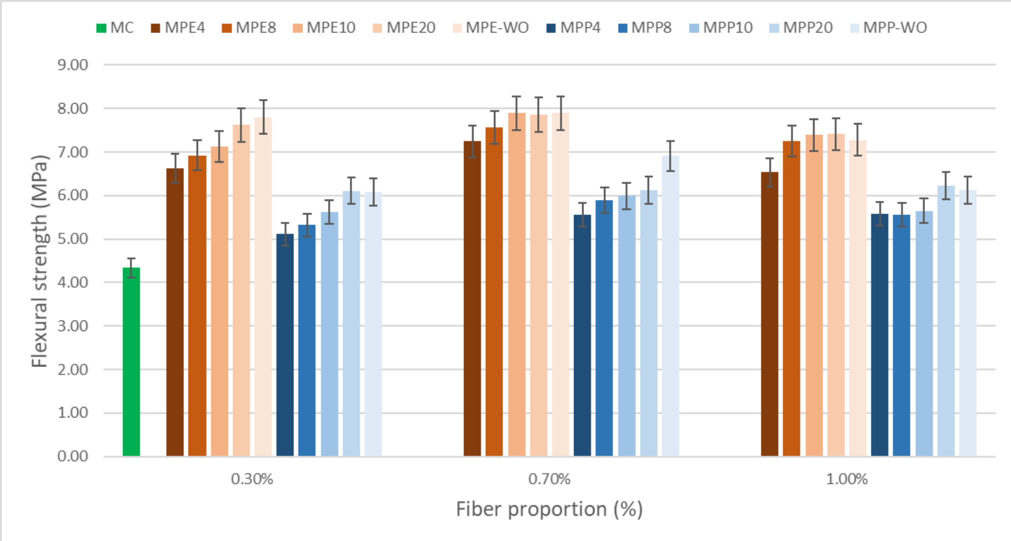

FIGURE 8. Results of the compressive strength test after 28 days of water curing for the controlled mortar, and the mortar with PE fibers and PP fibers.

When compared to PP fibers, PE fibers performed better in terms of both CS and FS. Both an increase in FL and FVF were associated with a modest drop in CS, with FVF being more noticeable. FS increased with FL but with FVF it increased up to 0.7% and started to decrease after 0.7%. Therefore, the findings show that the optimal formulation for enhancing the mechanical performance and workability of fiber-reinforced CC is a FL of roughly 20 mm (MPE-WO, FPP-WO) and a fiber proportion of 0.7%.

4. CONCLUSION

This study confirms the technical viability and environmental value of incorporating fibers derived from discarded fishing gear—specifically polyethylene (PE) from trawls and polypropylene (PP) from ropes—into cementitious composites. The sustainable natural cleaning method and efficient mechanical cutting process produced durable, well-graded fibers with over 95% tensile retention in alkaline conditions. Experimental results demonstrated that both fiber length and volume fraction significantly influence the workability, porosity, and mechanical properties of mortars. Notably, PE fibers at a volume fraction of 0.7% and length around 20 mm yielded optimal performance in terms of flexural strength and reduced porosity. These findings highlight a scalable and sustainable solution aligned with circular economic principles for valorizing marine plastic waste in the construction industry.

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