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Review Article

Use of waste fishing nets in cementitious applications

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Waste fishing nets cause severe detrimental impacts on the environment, as they are lost and abandoned in the ocean and on beaches yearly, harming the ecosystems. Most discarded fishing nets are made of non-biodegradable material, and dumping them into the sea or on land pollutes the environment. There is a growing demand for innovative and sustainable ways to reuse and recycle them into new product applications. Waste fishing nets can be used for reinforcing cementitious composites for structural and non-structural purposes to avoid these disposal problems. The inclusion of reinforcing fibers has significantly improved cement-based materials' physical and mechanical properties. When waste fishing nets are used as fiber, or mesh as it is, or as yarn, can meet the demands of the construction industry for a variety of products. The advancements in the usage of waste fishing nets as building materials are outlined in this paper. The review summarises current published literature about cementitious systems that contain waste fishing nets with an emphasis on their current management, fresh and hardened properties, and durability. Additionally, future research gaps on the behavior of waste fishing net reinforced composites for civil engineering applications are identified that contribute to the sustainability of the construction industry.

Keywords: Durability, Fishing net, Fresh properties, Fibers, Hardened properties

1 Introduction

Oceans are large bodies of water that cover around 71% of the earth's surface. As the foundation of the world economy, they support several businesses, including international shipping, tourism, and fishing. However, exploitative human meddling is causing damage to the marine ecosystem. A significant issue that must be addressed worldwide is the growing amount of marine trash[1,2,3,4]. The contamination of the seas and oceans with plastic is one of the critical problems[5,6] . According to estimates, roughly 10% of the entire marine debris generated worldwide is made up of lost or otherwise abandoned fishing nets[7,8] and, almost 10% of the waste produced globally is made up of plastic waste collected in the seas[9,10]. Globally, 640 kilo tonnes of discarded fishing nets contribute to ocean litter annually, according to the United Nations Environment Program report 2009[4].

The detrimental effects of abandoned fishing nets are that it floats in water for considerable distances at different depths[11] and can entangle marine animals such as whales, seals, fishes, birds, and other marine creatures which hurt them or drown them to death[12,13]. Waste fishing nets also obstruct sunlight, which impacts plankton and algae, two food sources for small marine life[5,14,15].

As the waste fishing nets badly impact marine ecology, these problems have sparked a global concern about discarding it in the ocean[16-20]. The fishing nets are generally composed of non-biodegradable materials that include nylon (polyamide, PA), high-density polyethene (HDPE), polyethene terephthalate (PET), and polypropylene[14,21-25] . Despite being discarded and subjected to harsh oceanic environments, the used fishing nets and trawls retain a high tensile strength[17]. The waste fishing nets are generally melted down and are used to create chairs, bags, bicycle seats, carpet tiles, sunglasses, jewellery, clothes, shoes, and home items[26]. They are also recycled to create recreational products[27], fashion, and footwear. 3D printing technology has been used by Hunt and Charter[28] to make leisure goods, fishing gear, and surf fins.

In terms of civil engineering application and construction practices, the waste fishing net may be used in soil, mortar and concrete as fibre reinforcement to enhance the properties[5,6,14,16,29]. Bituminous roads also employ residual nylon fibre for better abrasion resistance. When utilised as reinforcement in cementitious composites, the fishing net fibres are highly resistant to tensile and impact stresses[3,7,30-33]. To replace the synthetic polymeric fibers especially the polypropylene fibres, some researchers have tried to recycle waste fishing nets, primarily by adding the nets to soil- or cement-based materials to increase their strength and ductility[1,6,14,34].

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Considering the importance of converting waste fishing net to practical applications in cementitious systems elaborate review was carried out. Various aspects include potential methods and configurations to be adopted for using waste fishing nets in cementitious applications. Fresh, hardened, and durability aspects of waste fishing nets incorporated in cement mortar concrete were reviewed in detail. In addition, the existing practical applications and future opportunities are discussed.

2 Materials and Methods

2.1 Tailoring Waste Fishing Net for Concrete Applications

The recycling of waste fishing nets into structural concrete as a constituent material should have characteristics that enhance or sustain the properties of concrete. Fishing nets are generally used in cement mortar as short fibers in mortar matrix, textile fabric reinforcement, and also as FRP bars made from used nets[35]. The various methods[2,29] used to reuse waste fishing nets for cementitious application are depicted in Fig. 1.

2.2 Discrete fishing net fibers in concrete

Recycled waste fishing nets as short-fiber reinforcement in cementitious composites has been extensively investigated by many researchers[2,5,6,14,16,34,36,38] and improvement in flexural behaviour was reported[6,14]. Generally, fibers of size 20, 30, and 40mm were cut from the waste fishing nets and are widely used by researchers for investigations[2,29]. The fibers were added with the dry mix and blended prior to ensure uniform distribution and prevent balling[14]. Before the addition of the recycled nylon fibers in the production of repair mortars, the fibers were cleaned by soaking it in water, dried and manually cut to the required length[16]. Similarly, polyethene fibers were also cut mechanically to a length varying between 1-65 mm after prior cleaning by soaking in water.

he cut monofilament fibers were also used discretely to produce gypsum-based products[39]. It has also been found that the recycled nylon fibers from the waste fishing nets maintain the mechanical properties of virgin fibers. Other studies have also reported that waste fishing net fibers can show mechanical performance comparable to the commercial PP fibers[2,38]. Specifically, the twisted 40-mm-long macro-waste fishing net fiber exhibited higher replacement efficiency than commercial PP fibers with improved post-cracking behaviour at 1.0% of the fiber volume content.

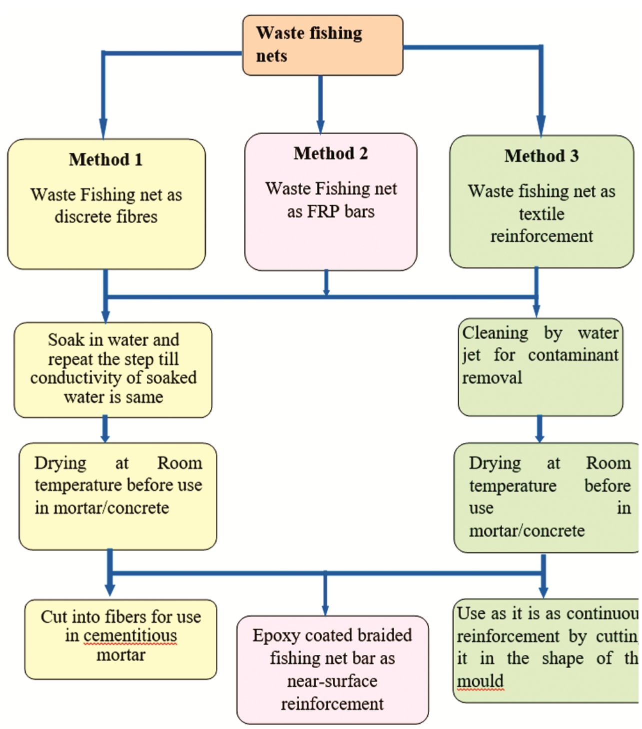

Fig. 1 — Various methods used for the reuse of waste fishing nets for cementitious applications

2.3 Fishing nets as FRP bars

The use of recycled nylon fishing nets to produce fiber-reinforced polymer bars used as near-surface mounted reinforcement for strengthening existing concrete structures was also reported[9]. Fiber-reinforced polymer (FRP) bars made of "Braided Polyethylene" of waste fishing nets were used as near-surface mounted (NSM) reinforcement, which is a method for strengthening existing concrete or masonry structures[1,17]. Waste fishing net strings were cut along the knots and were tensioned along the ends after being placed in the moulds that were milled with grooves of size 10 mm x 10 mm. After the placement of the fishing net string, the epoxy mixture consisting of resin and a hardener at a ratio of 1.7:1 were placed in the grooves. The hardened FRP bards were released from the groove and embedded in the concrete beams using a epoxy mixture. When these nets are used as reinforcement in concrete, they do not require any material re-polymerisation or extrusion[6,29] which can be advantageous in terms of processing time and cost.

2.4 Fishing nets as textile fabric reinforcement

In another study, polyethylene-based waste fishing nets were used as continuous reinforcement in a cement matrix[5]. The fishing nets after prior cleaning with water jet and drying, were cut according to the shape of the moulds to be used. A layer of mortar was placed and levelled before the placement of fishing net layer. According to the investigators, after the placement of the fishing net, a layer of mortar is placed, levelled and slightly vibrated to ensure penetration of the mortars into spaces between fishing net mesh. Successive layers were placed following the same procedure. Literature reports upto 4 layers of waste fishing net reinforcement in the mortars cast.

3 Results and Discussion

3.1 Characteristics of waste fishing nets towards concrete applications

Fishing nets are made from a variety of materials. The materials are generally non-biodegradable, neutrally buoyant synthetic polymeric fibers like high-density polyethylene (HDPE), polyethylene terephthalate (PET), or polyamide (PA)[40] with nylon (polyamide) and polyethylene being the most popular[41]. Amongst the fishing nets used around the world, 45.7 % of the nets are reportedly made of nylon, 27% nets are made of polyethylene and 13.6% are made of polyester[42]. Fishing net fibers can replace the macro synthetic fiber reinforcement often employed with cement-based materials having similar material type and surface shape[2]. From the manufacturer's perspective, the characteristics of each fishing line, which is made of around 40 fibres, are more significant than the characteristics of each fiber[1]. For unconditioned fibres, Young's modulus ranges from 1000 to 1040 MPa. If the fibres are assumed to be linear-elastic, the large strain and slope of the stress-strain curves demonstrate low stiffness[1]. According to Kim *et al.*[43], the mechanical bond strengths of straight, crimped, and embossed nets were 1.7, 3.9, and 5 MPa, respectively, showing the influence of fibers' surface characteristics on adhesion to cement.

3.2 Material types and their influence

Based on the commonly available fishing net types, it has been observed that waste fishing net made of polyethylene exhibits superior tensile and flexural resilience[5]. In comparison to the recycled PET fishing net fibres, recycled nylon fishing net fibres have advantages in terms of the first crack strength [44]. Nylon in cement mortar have reportedly improved the composite's toughness with higher fibre fractions and greater lengths of fibres. Ganesh Kumar *et al.*[45] concluded that the waste nylon fibres from waste fishing nets improved the ductile behaviour of concrete with 13 times greater toughness than the unreinforced cement mortar[46]. However, in terms of post-peak behavior, PET fibres were reported to be better with significant load reduction due to initial cracking but a second rising portion due to hardening of bond-slip behavior. Embossing of recycled PET fibers shows better performance of the post-peak behaviour, specifically with higher aspect ratio fibre. The fishing nets are deteriorated throughout usage [46-48] due to outdoor-environment, U.V exposure and continual load effects. The detrimental effects' influence on the characteristics of waste fibers and its comparison with fresh fibres are required. Investigations on the engineering characteristics of fishing nets made of high-density polyethylene (HDPE) were performed for new and waste fishing nets[1]. A Low Young's modulus (75-685 MPa) and high elongation at break (3-80%) for the braided polyethene were observed. Another study has found the tensile strengths for fresh and used fibers range from 403 to 445 MPa and 312-370 MPa[1] respectively. Peak strains ranged from 26-33% for both fresh and used fibers. The mechanical characterization of HDPE fishing nets collected from the seafloor revealed that macro waste fishing net fiber exhibited a 20% lower tensile strength than a new product fishing net (did not exposure the seawater), while theirmeasured elongation strain and Young's moduli were the same[1]. Table 1 enlists the various material properties of different fibers used in fishing nets.

3.3 Geometrical aspects and its influence

The embedded strength of the fishing net fibres in concrete depends on the fibers' physical characteristics and the surface, which is comparatively smooth and results in inadequate fibres adhesion to the concrete matrix. Fishing net fibres typically come in three geometries: braided multifilament (single or multi-yarn), twisted multifilament, and monofilament (single-yarn). The mechanical properties of cement-based materials produced with multifilament waste fishing net fibers were studied and it was reported that the use of multifilament waste fishing net fibers could significantly improve the post cracking load of fiber reinforced cementitous composites (FRCC) under a bending[29]. The multi-yarn waste fishing net fibers made by PE was found to improve the tensile behaviour of cement-based materials. The threads

Table 1 — Properties of waste fishing net fibers

References	Fiber Material	Tensile strength (MPa)	Young's Modulus (GPa)	Ultimate strain	Fiber diameter (mm)	Density (g/cm^3)
Orasutthikul *et al.*[14]	Recycled Nylon	440	3.0	Not available	0.35	1.13
Orasutthikul *et al.*[14]	Recycled -PET	450	20	Not available	0.7	1.32
Orasutthikul *et al.*[14]	PVA	900-975	23-27	Not available	0.2-0.66	1.3
Bertelsen *et al.*[1]	HDPE (new)	403-445	1.002	Not available	0.3	0.95
Bertelsen *et al.*[1]	HDPE (waste)	312-370	1.036	Not available	0.3	0.95
Bertelsen *et al.*[1]	P.E. fishing net	310-445	1.00	26-34%	0.27-0.33	0.95
ACI[71]	Polyethylene	75-590	5.00	3-8%	0.025-1	0.92-0.96
Banthia *et al.*[50]	Polyethylene	400	2.00-4.00	100-400	0.04	Not available
Kobayashi and Cho [72]	Polyethylene	200	5.00	Not available	0.9	0.96
ACI [71]	Polypropylene	135-700	3.50-4.80	15%	Not available	0.90-0.91
Banthia *et al.*[50]	Polypropylene	200-700	0.50-9.80	10-15%	0.01-0.15	Not available
Sun and Xu [73]	Polypropylene	560-770	3500	16-22%	0.1	0.91

used in fishing nets were found to have a much higher deformability (by about 15 times compared to welded wire steel mesh). The high deformation capacity of the fishing nets results from the low stiffness of the nylon material and the behaviour of the net knot[37]. Due to tightening and thread slippage, the knot causes the thread to distort. Because the failure is caused by the knot unravelling or the thread slipping through the knot, the presence of the knot in the fishing net reduces the thread strength. The threads and the fishing nets break down gradually, starting with one thread and spreading to the nearby strands. Furthermore, because it is made up of numerous twisted sub threads, the thread itself gradually fails[37]. By applying tensile stress to cement mortar, the effectiveness of recycled nylon fibers made from used fishing nets was evaluated[6]. It was concluded that waste fishing net fibers reinforced specimens positively converted the failure mode from brittle to ductile. The tensile strength of waste fishing net fibers, both straight and knotted, was examined. It was established that using straight net fibers resulted in less friction between the fibers and cement matrix, however, using knotted waste fishing net fiber was unsuitable because the fibers tended to ball up and become difficult to manage in their orientation[14].

3.4 Properties of waste fishing net incorporated concrete

3.3.1 *Fresh state properties*

Irrespective of the nature of the nylon strand in fishing net, whether straight or knotted, adding recycled nylon reduces the workability of mortar[14,16]. When the aspect ratio and fiber fraction rise, the mortar flow diameter for PET and PVA fibers falls. The flow diameter of mortar made from used fishing nets ranged from 183-247 mm for different fiber lengths. It has been observed that the flow diameter reduces as fiber length and quantity rise. Due to its balling action, which caused the separation of the fiber from the mortar, the fresh mortar containing knotted Recycled-Nylon fiber was observed to have a greater flow diameter. The inclusion of R-Nylon fibers was also observed to cause a 5–10% reduction in flow in other places[6,14]. Compared to other fibers, R-Nylon fibers generally tend to make mortar less flowable, evident from slump worsening when waste fishing net fibers was added to the cementitious matrix. The lowest slump of 175 mm was seen in the control combination that did not contain the waste fishing net fiber [49].

3.4.2 *Hardened state properties*

Incorporating of fibre in a cementitious matrix have been researched for several years and is said to improve the hardened state properties such as the toughness and impact resistance and also helps in controlling shrinkage cracking and permeability of the material[6,18,50]. It is well known that the role of fibers is not always the strength improvement. Some studies have confirmed improved post-cracking behaviour with no significant changes in the flexural and compressive strengths[49]. However, other studies have reported the effect of micro-PP fibers in improving the compressive strength[19,49,51,52]. In relevance to this study, the effect of utilization of various types of waste fishing nets on hardened properties of concrete is summarized in this section.

The compressive strength of hardened concrete is found to be affected by the inclusion of waste fishing nets in concrete. In a study reported by Ottonsen et al., the compressive strength of two different lengths of recycled Nylon fibre (2 and 4 cm) reinforced mortar was lower than the reference mortar[29]. The results also indicate that compressive strength decreases as length of the fibre decrease and as the amount of R-Nylon fibre increases. The compressive strength was reported to decrease with the addition of plastic fibres since the fibres assume the role of voids in the cementitious matrix[6,14]. Furthermore, when the specimens are subjected to compressive load, lateral strain is induced in the mortar due to the poisson's effect. As the load increases, longer fibers play important role in mortar's lateral tensile strength than the shorter ones[14]. Similar reports of reduction in the compressive strength of repair mortar consisting of recycled nylon fibers were reported by Srimahachota *et al.*[16]. Reduction in compressive strength of upto 37% was noticed when very short fibres were employed[6]. Another experimental study investigated the effects of different waste fishing net-fiber types, the geometries, and fiber volumes on the compressive strength and tensile resistance of FRCCs[2]. The replacement efficiencies of the waste fishing net-fibers for reinforced mortar were also examined based on comparisons with commercial PP fibers. The compressive strength of FRCCs generally decreased as the volume fraction increased, except for the set of waste fishing net1-FRCC samples which had a straight yarn with smooth surface. Additionally, WFN3-FRCCs which were constructed with twisted yarns exhibited the highest compressive strength (67.8 MPa) at a constant volume fraction of 0.5%, while the WFN1-FRCC samples exhibited their highest compressive strength (62.3 MPa) at a constant volume fraction of 1.0%. The reduction in the compressive strength was attributed to the interfacial bond between the fibers and the matrix. Another reason cited for loss on compressive strength with deceased length was the the low Young's modulus of the Nylon fibers when mixed with recycled nylon fibre. In another study, the hybrid effect of waste fishing net hybrid fiber-reinforced cementitious composites (WFN-HFRCCs) was experimentally investigated[49] using three different waste fishing net fibers viz the 40 mm macro-waste fishing net fiber and two micro-waste fishing net fibers at two different mix compositions (1.0%, 0.5 + 0.5%). It was observed that hybrid fiber-reinforced composites exhibited improved performance when compared with single fiber-reinforced composites. Different types of PP fibers dispersed in cementitious composites bonded well with the cement matrix, and these improved the mechanical behavior by withstanding greater stress under compression and showed lower drying shrinkage strain[49].

The compressive strength, split tensile strength and flexural strength of concrete reinforced with waste fishing nets are directly correlated with increased nylon fibers percentage. Padhe and Panganti[59] found out that lower grade of concrete M15 showed improved strength when added with waste fishing nets compared to M20 and M25 mixes.

The tensile strength of the cementitious matrix embedded with waste fishing nets were also studied by various authors. The studies reported enhancement in the tensile strength of the cement based materials while using recycled waste fishing net fibres. However, it was also reported by the authors that the tensile strength of the cementitious composites was lower after the first cracking when compared with similar composites produced with commercial PVA fibres[2]. The interfacial bond strength between the fibers and cementitious material was stated as an essential parameter, although the tensile strength of the fibers is a parameter that can improve the tensile strength of FRCCs. Experimental study using the R-nylon fibres improved the tensile strength (upto 35%) of R-nylon fibre reinforced mortar and improved the fracture properties by exhibiting a ductile failure mode[37]. Subsequently, the effectiveness of both straight and knotted waste fishing net fibers as tensile reinforcements was investigated to produce a fiber-reinforced mortar. It was confirmed that the use of straight waste fishing net fibers led to a low frictional resistance between the fibers and cement matrix, while knotted waste fishing net fiber was impractical because the fibers tended to form balls, making their orientation difficult to control[14].

Results show that a higher percentage of fibers (1.5% rather than 1.0%) causes a less noticeable drop in the load after the peak value, while higher fiber aspect ratios give the reinforced mortar a hardening-type post-peak behaviour. As a result, remarkable increments of the toughness indices and the residual strength factors were observed when the percentage of fibers (from 1.0% to 1.5%) and the fiber length (from 0.5 in to 1.0 in and 1.5 in) was increased. From the review of results in existing literature[26,43,49], it was concluded that the toughness and ductility properties of mortars and concretes significantly benefit from the addition of R-Nylon fibers in terms of first-crack strength, as compared to the recycled nylon fibers obtained from post-consumer textile carpet waste [53] and recycled PET fibers[11,26,36,37,42,45,54-59]. According to another study[54], the fiber reinforced cement mortar

(FRCM) composite overlays reinforced with fishing nets was found to have comparable strength, between 72 – 120 %, to that of counterparts having welded wire steel mesh (WWSM) reinforcement. SEM images suggest effective interfacial bond between the mortar and the fishing net and WWSM reinforcement. The bond characteristics of the fibres observed were influenced by the length, aspect ratio, surface finish and chemical adhesion of the fibers with mortar. Higher tensile strength values attained by the composites were attributed to the mortar role in better distributing the load to the reinforcing threads[54].

The flexural strength of the mortar specimen consisting of R-Nylon fibres was reported to be slightly lower compared to the reference samples. However, improvement in the post peak behaviour was noticed along with a toughness index value of 2.4-3.4 MPa[29]. Contrarily, Orasutthikul *et al.*[14] observed an improvement in the flexural strength of 22-41% in recycled-Nylon fibre mortars in comparison to that of recycled PET and PV fibre. The post peak behaviour was found to be influenced by the characteristics of the fibres such as tensile strength, geometrical shape, young's modulus etc. In case of repair mortars, when the recycled nylon short fibres were used, the resulting material enabled to sustain more flexural load after the peak. The repair mortar retained a table post-peak load of ~13.6% of the yield load and prevented abrupt failure of the beams[16]. Spadea *et al* [6] observed from their experimental studies that mortar reinforced with recycled nylon fibres from waste fishing nets produced higher first-cracking flexural strength and fracture energy than plain mortar. The fiber was found to effectively increase the flexural strength upto 35%. Flexural strength is enhanced upto 41% for optimum fiber fraction of 1.5% [60]. The tensile and flexural behaviour of waste fishing nets used to reinforce cementitious composites were studied by Truong *et al.*[5] The nets were used as continuous reinforcement, cut to the shape of the moulds. The tensile strength and the flexural resistance of the polyethylene waste wishing net reinforced mortar was found to improve when four layer of the net was used as continuous reinforcement in matrix. Though the commercial textile reinforced concrete were found better in properties, four layers of waste fishing nets reportedly produced pseudo tensile-strain hardening behaviour[5].

Experimental research was done to assess the hybrid influence of waste fishing net fibers on the flexural response of waste fishing net hybrid fiber-reinforced cementitious composites. In order to examine the hybrid effect, macro and micro fibers were combined with cementitious matrix[49]. When compared to single fiber-reinforced composites, hybrid fiber-reinforced composites performed better. The tensile resistance of cementitious composites made from waste fishing net was compared to commercially produced macro fibers by PE and PP. Waste fishing net fiber reinforced concrete outperformed its single waste fishing net reinforced counterpart in terms of flexural toughness by 29% and residual strength by 78%. Maximum compressive, flexural and residual strength were found in reinforced samples made from hand-cut macro waste fishing net fibers and ground up waste rope fibers. From the increased strength and ductility under flexural load, the hybrid effect of the waste fishing net fibers was confirmed[49].

3.4.3 Durability aspects

The durability assessment of nylon 6, polypropylene, and polyester[54,61] shows that polyester is less resilient in alkaline environments than nylon or polypropylene. A leaching test simulates the release of pollutants by subjecting a reagent to a leaching agent for a predetermined period[37]. The test concluded that R-Nylon fibers may not significantly affect the environment and are suitable for use in the reinforcing phase of cement materials without risk. In a separate investigation, conditioned R-nylon monofilaments were used to alkali condition R-nylon fibers in an alkaline environment. A mass loss of around 1.7% was observed, but there were no significant corrosion symptoms on the fiber surface[37].

Fishing nets made of polyethylene are hydrophobic with outstanding alkali resistance qualities in cementitious systems[50]. Recycled polyethylene terephthalate (PET) as fiber reinforcement into cementitious mortar was found to improve mechanical and chemical resistance and regulate plastic shrinkage [6,44,60,62-65]. According to the exposure area, time, and environmental factors, such as high temperatures, trash fishing net type, size, and material qualities of waste fishing net can vary significantly[66]. The cement matrix and various PP fishing net fiber types dispersed in cementitious composites formed a strong bond that improved the mechanical performance by withstanding more stress during compression and exhibiting less drying shrinkage strain[67]. The reduction of free shrinkage by 25% in comparison to control was proven by the use of micro-waste fishing net fibers. Utilizing discarded fishing net PP fibers, which have excellent ductility, fineness, and dispersion qualities, can help prevent plastic cracking[69]. Hybrid fibre reinforced composites made from hand-cut macro waste fishing net fibers and ground up waste rope fibers possessed shrinkage and fast chloride penetration test results that did not significantly increase[49]. Waste fiber net reinforced concrete can be made more durable and brittle by adding silica fume as a mineral additive[67,70].

3.5 Present status and future opportunities for the use of waste fishing nets in cementitious applications

The significant potential for material recycling in nylon nets makes them an excellent choice for reducing non-biodegradable trash. The flexibility of the fishing net allowed it to be applied easily to masonry surfaces by being embedded in cementitious mortar. The fishing nets were utilised in the form of continuous fiber mesh for masonry mortar reinforcement. In civil engineering, using fishing nets as internal reinforcement for overlays is an innovative method of reinforcing and repairing structural elements. By applying cementitious overlays strengthened with fishing nets, subpar masonry walls' in-plane flexural strength can be improved to withstand strong winds. The out-of-plane capacity provided by such a system is equivalent to that offered by its counterpart, a steel mesh reinforced overlay, which is often used[37]. However, it is discovered that the overlay reinforced with fishing nets performs better than the typical system in terms of deformability and, subsequently, the energy-absorption capacity. The data generated in the investigations of[37] attests to the unique fishing net reinforced overlay's ability to upgrade masonry walls against high wind pressures and the impact of flying debris during hurricanes and tornadoes. Additionally, the reinforced overlay can be utilised to insulate masonry constructions from heat and sound.

The near-surface mounted reinforcement made from fishing nets with epoxy were cast into the concrete beam's surface grooves. The near-surface mounted fiber-reinforced bars constructed of fishing nets are used to minimise the development of fractures. The aforementioned usage demonstrates that FRP fishing net bars have a negligible beneficial impact on the concrete beam's flexural and shear strength and crack growth[17]. The issue ofepoxy coated FRP bars made from fishing nets to reinforce pre-existing concrete structures is the epoxy coating protects the nets from deterioration in the concrete's alkaline environment and creates a strong bond between concrete and FRP bars. Epoxy is poisonous, challenging to install properly, and expensive to import; therefore, importing a substance with such negative economic and environmental effects seems irrational. Future research should concentrate on developing FRP bars without epoxy coating and examining how quickly nets degrade in alkaline settings. Though there is potential in using fishing nets as FRP bars to strengthen existing concrete structures, much future research is required before it can be implemented as a reliable reinforcement method[17].

Additionally, the make-up of fishing net lines is from twisted or braided fibers, therefore no need for processing beyond just trimming the nets to the required length[1]. The peak strength at which the first fracture occurred lowered, and the post-crack load increased when polyethylene fibers from old fishing nets were utilised discretely[39]. It is feasible to employ such nets in cementitious systems in their natural net form itself with the development of composite materials like textile-reinforced concrete. In this context, it is possible to study hybrid textiles manufactured from waste fishing nets and other textile materials in a hybrid way.

Fishing nets are designed to be utilised in developing country coastal communities[37]. The FAO estimates that 90% of fishing industry workers are concentrated in small-scale groups in developing nations. These groups can be expanded to create supply chains and more opportunities for a variety of product applications.

4 Conclusions

Waste fishing nets that haven't undergone any processing are categorized as low-modulus fibers. These unprocessed waste fishing nets, when used as reinforcement, are less likely to increase strength than they are to help absorb much energy, increase toughness, and lessen shrinkage cracking in young concrete. The use of straight or twisted recycled nylon fiber in mortar lowers its workability. It has been observed that adding a used fishing net increases toughness, impact resistance, and post-cracking behaviour and reduces shrinkage cracking. The smooth surface of the fibers may cause poor bonding between the fibers and the cementitious matrix, according to an analysis of the mechanical properties of waste and new high-density polyethylene fibers from fishing nets. The ultimate elongation strain and Young's modulus of waste fibers were essentially unaffected, but their tensile strength was discovered to be 20% lower than that of fresh fibers. The deformation capacity of nylon multifilament fishing nets is more significant due to the high deformation with lesser stiffness of the nylon material. Fishing net knots are made by adding a thread to the net, deforming through the thread slipping from knot or the knot tightening caused by the mesh specimen's geometric design. The broader specimens of the geometric design with inherently unequal stress distribution exhibit more significant deformations.

Waste fishing nets can be used to strengthen the NSM technique and construct overlays for masonry structures. Such systems delay the onset of cracks while increasing flexural strength. More research in recycled fishing nets is necessary to reinforce concrete more thoroughly. Due to the toxicity of epoxy, studies must concentrate on producing FRP bars without coating. With the advancement of composite materials like TRC, it is now conceivable to employ such nets in building items in their natural net form and combine them with other fiber net arrangements.

Studies are required regarding cleaning, pre-treatment, quality control of recycled fibers, and durability against more prolonged exposure before finalizing the applications in cementitious systems. Waste fishing nets undergo degradation of properties due to continuous load impacts while fishing and exposure to other environmental factors. The recycled waste fishing nets are generally cut by hand for their use as fiber in cementitious systems, which is time-consuming and unsuitable for real-time application. Therefore, machinery is required for their processing and mass production. Suitable Pre-treatment of fibers is necessary in order to improve the bond behaviour between the fibers and cement substrate. Though recycling waste fishing nets for use as fiber reinforcement is an effective solution, the type, size, and material properties vary greatly depending on the exposure area, period, and environmental conditions, including high temperature, which necessitates elaborate experimental studies for its successful reuse.

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