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Effectiveness of recycled nylon fiber from waste fishing net with respect to fiber reinforced mortar

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HIGHLIGHTS

- The effects of recycled nylon fiber mixed in mortar on flexural behavior are focused.
- Improvement of flexural strength and toughness are observed by using recycled nylon fiber.
- Post peak behavior is directly affected by bond strength between fiber and matrix.

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ABSTRACT

This paper discusses the utilization of recycle waste fishing nets in fiber reinforced mortar. Experimental test results compared the mechanical properties of such mortar made with recycled nylon fiber to those of such mortar made with recycled PET and PVA (polyvinyl alcohol) short fibers. The recycled nylon (R-Nylon) fibers were obtained by manually cutting of waste fishing nets to the lengths of 20 mm, 30 mm and 40 mm. Two types of R-Nylon fibers were investigated that are straight and knotted types. The addition of straight R-Nylon fiber improved the flexural strength up to 41% in comparison with that of the knotted R-Nylon, recycled PET, and PVA fibers. The compressive strength of the mortar with R-Nylon fiber decreased with increase in fiber fraction and length. The post peak load, toughness and residual strength depended on the properties of fiber such as Young's modulus, tensile strength, and geometry as well as the bond strength between fiber and matrix.

1. Introduction

Marine debris is one of the major problems in the sea and ocean environment. It has been reported that more than half of the debris that were dumped or lost directly into the seas, about 640,000 tons, are fishing nets [1]. Almost 700 marine species including marine mammals are at risk; in particular, large whales, seals, and sea lions have been found entangled in the fishing nets [2]. These abandoned fishing nets and debris also disturb marine ecosystem. They block sunlight to reach smallest creatures in the sea, which directly affects marine animals that feed on smallest creatures such as algae and plankton. Nowadays, fishing nets are mostly made of nylon which is non-biodegradable, and totally entangled fishing nets are very difficult to be separated. Therefore, there have been strong calls for recycling waste fishing nets. To meet such demands, a practical, suitable way to recycle them has been sought by many companies, while using recycled and renewable materials have been paid more attention [3]. The waste fishing nets are used in manufactures of carpet tiles, as well as they are melted and then used in manufactures of bicycle seats, chair and luggage castors, tool handles, electronics components, and other goods [4]. The nets have been also used in civil engineering field as a recycled fiber in order to reinforce or strengthen concrete, mortar and soil [5,6]. Even during the past three decades, the use of synthetic fiber, such as polyvinyl alcohol (PVA) fiber and polypropylene fiber has been paid attention, and it is successful in significantly improving mechanical properties, such as flexural strength, fracture toughness, and impact resistance, of fiber reinforced mortar and concrete [7–22]. However, using of those fibers surely leads to higher energy consumption and emission for production process [6]. Accordingly, many researchers have been concerning and focusing on using recycled materials [21,23–29], in recent years. Kim et al. [5] studied the mechanical properties of reinforced lightweight soil (RLS) by using waste fishing nets. They found that using waste fishing nets at 0.25% by weight of soil makes unconfined compressive strength of RLS 2–2.5 times higher than that of untreated lightweight soil. Spadea et al. [6]

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investigated the static mechanical properties of fiber reinforced mortar by using recycled nylon fiber from abandoned fishing nets. They found that the toughness and ductility are significantly improved by the addition of recycled fiber to the mortar, and the flexural strength is improved up to 35%. Alkali degradation of the nylon fiber may occur if it is mixed with cement, which results in reduction in strength and toughness of the fiber reinforced concrete. Ochi et al. [30] investigated the alkali resistance of synthetic fibers such as PET, polypropylene and PVA fibers by doing immersion tests into alkali solution. They found that tensile strength of PET, polypropylene and PVA fibers decrease 99%, 86% and 56% of respective virgin fibers. For the recycled nylon fiber, Spadea et al. [6] found that its tensile strength decreases only about 4% by the exposure to an alkali environment. The authors previously conducted a comparative experimental research on the effectiveness of recycled nylon fiber and PVA fiber reinforced mortar [31]. The research concluded that recycled nylon fiber has a potential to improve the mechanical properties of mortar.

This paper investigates in detail the effectiveness of recycled nylon fibers from waste fishing nets when they are mixed into mortar. Change in flow diameters of fresh mortar was investigated to discuss the workability of the fiber reinforced mortar. Compressive and flexural strengths of the recycled nylon fiber reinforced mortar were measured and compared with those of mortar with recycled PET and PVA fibers that have been frequently used as reinforcing materials of mortar and concrete. In addition, the surfaces of fibers after the bending test were carefully observed by using microscope to understand the mechanism of the mechanical properties improvement.

2. Experimental program

2.1. Mixture composition and preparation

The recycled nylon fiber examined in this study was prepared by manually cutting waste fishing nets collected by fishermen in Hokkaido, see Fig. 1(a). The cutting was started after washing the net by tap water. The two fiber types were made; that is, straight fiber and knotted fiber, see Fig. 1(b) and (c), respectively. The straight fiber was 20 mm, 30 mm or 40 mm long, and was mixed in mortar at the volume fractions of 1.0%, 1.5% and 2.0%. The knotted fiber was 40 mm long, and was mixed in mortar at the volume fractions of 0.5%, 0.75% and 1.0%. The volume fractions of the knotted fiber are less than those of the straight fiber because the knotted fiber tends to form tenacious balls easily. The PVA and recycled PET fibers were mixed in mortar at the volume fractions of 1.0% and 1.5%. In this study, the uniaxial tensile tests according to ASTM C1557-03 were carried out to determine Young's modulus and tensile strength of recycled nylon fiber, as shown in Fig. 2. The appearances and properties of all the fibers are summarized in Fig. 1 and Table 1, respectively.

Firstly, cement and sand were mixed by using small mixer, and after that, fibers were gently added to prevent the formation of fiber balls. To ensure uniform fiber dispersion, all dry components were mixed by hand. Then, water was gradually added to the mix, and the mixing was continued to blend all ingredients for other 2 min so that a homogeneous mixture and proper workability were achieved. The mass ratio of sand with cement of the mortar was 3.0 and the water-to-cement ratio was 0.5. All molds were covered with plastic sheet to minimize moisture evaporation for a period of 24 h after placing. Subsequently, the specimens were cured in a water tank at 20 ± 2 °C for 28 days. As presented in Table 2, the mortar mixes vary due to types, volume and the aspect ratio of fiber. The unreinforced mortar is denoted as UR, and the fiber reinforced mortar specimens are noted as "KN", "SN", "PE" and "PV," followed by "fiber length – volume fraction," to represent recycled knotted nylon fiber, recycled straight nylon fiber, recycled PET fiber and PVA fiber, respectively.

2.2. Testing methods

The mortar flow test was conducted in accordance with ASTM C 1437 [32]. Compressive strength was determined in compliance with ASTM C 39 [33]. Flexural strength tests were conducted in accordance with ASTM C 1018 [34]. The authors performed three-point bending tests, and measured the peak load, first crack strength, toughness indices and residual strength factors. Two Linear Variable Differential Transformer (LVDT) were used to measure deflection, and were installed each side of the specimen at mid-span, as shown in Fig. 3. For each mix design, the mortar was cast in cylinders of 50 mm diameter × 100 mm in height for the compressive test and in prism molds of 40 mm × 40 mm × 160 mm for the bending test. For each mix, three and two specimens were tested for compressive and flexural strengths, respectively, after curing for 28 days.

3. Results and discussions

3.1. Flowability

The flow diameters were measured and are listed in Table 2. It can be seen that the flow diameter tends to decrease with increase in fiber length and amount. Moreover, if comparing 1% volume fraction of straight and knotted R-Nylon fiber, the fresh mortar with knotted fiber has larger flow diameters. According to balling of KN fiber, which resulted in fiber-mortar separation, the mortar easily flow. For PET and PVA fibers, mortar flows exhibited the same results; that is, when the aspect ratio and fiber fraction increase, the flow diameter decreases. Furthermore, if comparing R-Nylon, PET and PVA fibers at the similar aspect ratio and the same fiber fraction, addition of R-Nylon, PET and PVA fibers into mortar results in more reduction in mortar flowability.

3.2. Compressive strength

The compressive strengths of the fiber reinforced mortar at 28 days are presented in Table 3. The results indicate that the compressive strength decreases as the length decreases and as the amount of R-Nylon fibers increases. This can be explained that Young's modulus of mortar was reduced with the dosage of fibers with low Young's modulus, especially R-Nylon fibers [35,36]. The Young's modulus of R-Nylon fiber is very low compared with that of mortar; therefore, inclusion of the fiber creates voids in mortar [37]. This might suggest that the lower compressive strength of the KN mortar is the result of a greater reduction in Young's modulus of the fiber reinforced mortar from the inclusion of knots, see Table 3. Additionally, poor fiber distribution according to easy forming ball of KN fiber, this results in reduction in compressive strength of KN mortar. Palmquist et al. [38] found that the addition of fiber, especially long fiber, leads to increase in the volume of interfacial transition zone which results in reduction of strength and stiffness of fiber reinforced mortar. Li [39] also investigated the effect of fiber addition on compressive strength of cementitious composites. In this work, it can be explained that a decrease of compressive strength is a result of low resistance to sliding of crack faces which is exerted by bridging force of fiber. Furthermore, when the specimens are subjected to compressive load, it induces lateral tensile strain in mortar due to the Poisson effect. As the load increases, longer fibers play an important role in mortar's lateral tensile strength than shorter ones. Therefore, the mortar postpone