平成27年度　土木学会北海道支部　論文報告集　第72号

Effect of recycled nylon fiber on mechanical properties of mortar

Graduate School of Engineering, Hokkaido University　Student Member　Shanya Orasutthikul
Faculty of Engineering, Hokkaido University　Fellow　Hiroshi Yokota
Faculty of Engineering, Hokkaido University　Member　Katsufumi Hashimoto
School of Engineering, Hokkaido University　Student Member　Daiki Unno

1. INTRODUCTION

Disposing of fishing nets has been a major concern in the sea environment. The number of abandoned fishing nets is remarkably increase in every year. Separating the nets for disposal is not practical because they become totally entangle. In addition, there were found about 705,000 tons of fishing nets in the North Pacific Ocean [1]. The marine life, especially turtle, seal and other marine mammals are directly affected, they can be entangled in these abandoned fishing nets. In addition, the nets also disturb the marine food web by blocking sunlight to reach the plankton and algae below the surface of the ocean. This will straight affect the animals that feed on algae and plankton. Nowadays, fishing nets are mostly made of nylon 6 which is not biodegradable. Although the storage of them does not cause any danger, it is very important to find the suitable way for recycling them. Saverio et al. [2] investigated the use of recycled nylon fiber to reinforce mortar. They observed that the toughness and ductility significantly improved from the addition of recycled reinforcing fibers to the mix-design.

In this study, the authors studied mechanical properties that are compressive strength, flexural strength and toughness of different fibers containing mortar composites. The main objective of this study is to investigate the effectiveness of recycled (R)-nylon fiber from waste fishing in enhancing the mechanical properties of mortar.

2. METHODOLOGY

The waste fishing nets in this experiment were collected by fishermen in Hokkaido, Japan. The nets were cut by hand at difference sizes of 20 mm, 30 mm and 40 mm. Fiber content in mortar were 1%, 1.5% and 2% by volume. After mixing cement and sand by small mixing machine, fibers were gently added to prevent forming fiber balls. Then, all dry components were mixed by hand in order to obtain a uniform distribution of fibers. Water gradually added, and used mechanical mixer to blend all mixture at low speed for 2 minutes until a homogeneous is achieved. The resulting mixture was then cast into 40 mm x 40 mm x 160 mm molds for flexural strength test and 50 mm x 100 mm cylinders for compressive strength test. The specimens were covered with the plastic sheet for a period of 24 hours before they were demolded. After that they were cured in a water tank at 20 ºC until 28 days, the specimens were tested. As listed in Table 1, the mortar mixes vary due to the volume and aspect ratios of fibers. The unreinforced mortar was referred as UR, and the reinforced mortar specimens as “R-ny” fiber length – volume fraction.

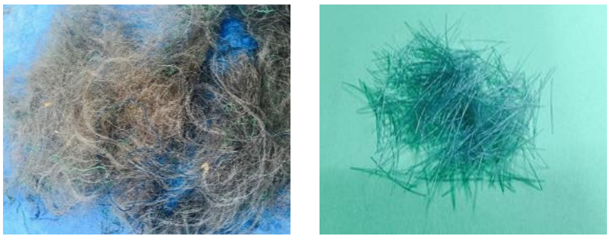


Fig. 1 Recycled nylon fiber from waste fishing nets

Table 1 Types of specimen

Types of specimen	Fiber fraction by volume (%)	Fiber length (L) (mm)	Diameter (D) (mm)	Aspect ratio (L/D)	Flow (mm)
UR	-	-	-	-	237
R-ny20-1	1	20	0.39	51	218
R-ny20-1.5	1.5	20	0.39	51	209
R-ny20-2	2	20	0.39	51	205
R-ny30-1	1	30	0.39	77	216
R-ny30-1.5	1.5	30	0.39	77	205
R-ny30-2	2	30	0.39	77	188
R-ny40-1	1	40	0.39	103	210
R-ny40-1.5	1.5	40	0.39	103	207
R-ny40-2	2	40	0.39	103	182

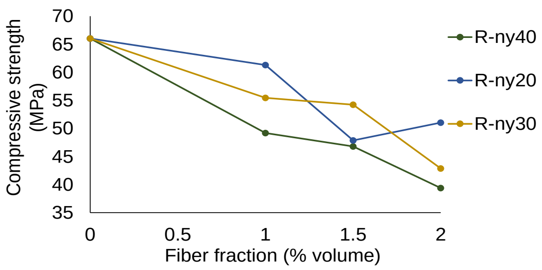


Fig. 2 Compressive strength of R-nylon reinforced mortar

3. MECHANICAL STRENGTH AND RESULTS

3.1 Effect of fiber content and fiber length on compressive strength

Cylinders were tested in compression in accordance with ASTM C39-96. The compressive strength of all types of fibers with various fiber containing mortar are listed in Table 2. It can be obviously seen in Fig. 2 that increase in the length and amount of recycled nylon fiber decrease the compressive strength. Elastic moduli of mortars were reduced with the dosage of low modulus elasticity fiber were included [3, 4], and addition of fibers as though created voids in mortar specimens [5].

3.2 Effect of fiber content and fiber length on flexural strength

After the specimens were cured for 28 days, three points bending test were conducted according to ASTM C 1018.

The results of three points bending test including the peak load, deflection at the peak load and the first crack strength are presented in Table 3. It can be observed that addition of recycled nylon fibers into mortar improved the first crack strength up to 41%. The first crack strength can be determined as modulus of rupture as follows:

$$R = PL/bd^2$$

Where
R = modulus of rupture
P = maximum applied load indicated by testing machine
b = average width of the specimen at the fracture
d = average depth of the specimen at the fracture
L = span length

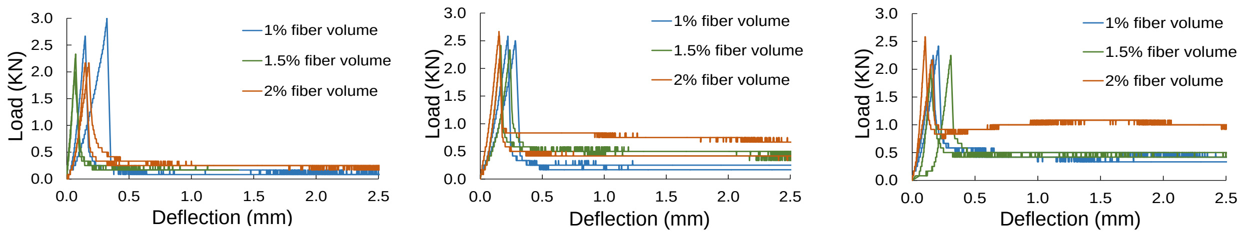
From Fig. 3 (a)-(c), R-nylon fiber reinforced mortars show relevant drop of the load after first crack occurred. The main reason may be concerned with the geometrical shape of the fibers. Kim et al. [6] carried out an investigation focusing on the effects of the geometry of recycled PET fibers on mechanical bond with cement based. In the mechanical bond test, the embossed fiber had hugely superior performance to the other types (straight and crimped). The R-nylon fibers surfaces were examined after bending test to analyze the frictional resistant force. As shown in Fig. 4, the fiber surface had no significant change in scratching, it means that R-nylon fiber has low mechanical and chemical bond strength.

3.3 Effect of fiber content and fiber length on toughness

According to ASTM 1018, the toughness indices I_5, I_{10} and I_{20} are obtained by dividing the energy absorbed to a certain

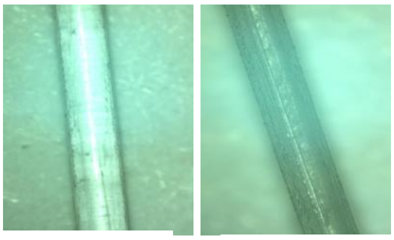
Table 2 Results of compressive and flexural strength

Types of Specimen	Compressive strength test				Flexural strength test				
	f_c	SD	CV	$\triangle f_c$	P_{cr}	R	SD	CV	$\triangle R$
	MPa	MPa	%	%	kN	MPa	MPa	%	%
UR	66.05	3.25	10.61	-	2.00	3.75	-	-	-
C-20-1	61.32	4.81	7.85	-7.16	2.83	5.31	0.24	8.31	41.68
C-20-1.5	47.87	2.56	5.36	-27.52	2.17	4.06	0.23	10.78	8.25
C-20-2	51.04	4.23	8.29	-22.72	2.17	4.06	0	0	8.35
C-30-1	55.46	2.13	3.84	-16.04	2.29	4.30	0.29	12.87	14.58
C-30-1.5	54.23	3.13	5.77	-17.90	2.37	4.45	0.06	2.59	18.68
C-30-2	42.88	2.63	6.12	-35.07	2.42	4.53	0.35	14.63	20.85
C-40-1	49.18	7.12	14.47	-25.54	2.34	4.38	0.12	5.15	16.75
C-40-1.5	46.80	8.62	18.42	-29.15	2.13	3.98	0.18	8.32	6.25
C-40-2	39.40	3.40	8.63	-40.34	2.38	4.45	0.29	12.39	18.75



(a)　20 mm R-nylon fiber　(b) 30 mm R-nylon fiber　(c) 40 mm R-nylon fiber

Fig. 3 Load-deflection curve of mortar specimen reinforced with recycled nylon fiber



(a) Before (b) After

Fig. 4 Surfaces of fibers before and after flexural test.

multi of first crack deflection 3.0, 5.5 and 10.5 respectively, by the energy absorbed up to the first crack. Toughness indices and residual strength factors are presented in Table 3. The results came as no surprise that addition of fiber into mortar appears to have remarkable improvement on toughness property, especially when fiber fraction and aspect ratio increased. Similar to post peak behavior, the toughness property is also dependent on fiber characteristics, such as geometrical shape, tensile strength and Young's modulus as well as interfacial bonding strength between fiber and cement.

4. CONCLUSIONS

The effectiveness of three types of fiber were examined. The compressive and flexural test was used to quantify compressive strength, modulus of rupture, post peak load, toughness indices and residual strength factors.

As evident from this study, the effectiveness of recycled nylon fiber reinforced mortar indicated the following:

1. It was made clear that the recycled nylon net has potential for use in mortar as an additive to improve its structural capacity.
2. Addition of recycled nylon fibers in to mortar leads to 7-40% reduction in compressive strength as the volume fraction and aspect ratio of fiber increased.
3. Recycled nylon fibers from waste fishing net improve modulus of rupture (first crack strength) up to 41.7%. The fiber reinforced mortars move the failure mode from a brittle fracture to more ductility.

Table 3 Toughness indices and residual strength factors at 28 days

Types of specimen	Toughness Indices			Residual strength factors	
	I_5	I_{10}	I_{20}	$R_{5,10}$	$R_{10,20}$
R-ny20-1	1.7	2.0	2.4	6.0	4.2
R-ny20-1.5	2.1	2.6	3.4	9.9	8.5
R-ny20-2	1.9	3.0	4.6	21.9	15.4
R-ny30-1	1.9	2.6	3.8	13.3	12.5
R-ny30-1.5	2.6	4.1	6.9	29.6	27.9
R-ny30-2	2.4	3.8	6.1	26.6	23.6
R-ny40-1	2.2	3.5	5.3	25.9	17.9
R-ny40-1.5	3.0	5.0	9.1	40.6	40.8
R-ny40-2	3.0	5.0	10.0	41.7	50.0

4. The post peak load, toughness indices and residual strength factors increase as increase in the amount and aspect ratio of R-nylon fiber.
   It has to be remarked, however, that recycled nylon fiber reinforced mortar analyzed in this study prove to be beneficial in terms of first crack strength and material toughness as virgin fiber. Although, a higher fiber fraction may be required to match the performance.
5. The use of recycled nylon fibers are beneficial in term of environmental effect. There is no energy consuming process requirement in this study. The fishing nets were collected and manually cut. Moreover the use of recycled fibers consequently reduce product cost.

The expansion of this research, the authors look forward to considering an admixture to increase fiber-matrix bond strength.

5. REFERENCES

[1] One Green Planet: -http://www.onegreenplanet.org (Mar. 4, 2015)

[2] Spadea S., Farina I., Carrafiello A., and Fraternali F. (2015) *"Recycled nylon fibers as cement mortar reinforcement."* Construction and Building Material, 80, 200-209

[3] Wang Y., Wu H. C., and Li V. C. (2000). *"Concrete reinforcement with recycled fibers."* Journal of Materials in Civil Engineering, ASCE, 314-319.

[4] Hu W., Yang X., Zhou J., Xing H and Xiang J. (2013). *"Experimental research on the mechanical properties of PVA fiber reinforced concrete."* Research Journal of Applied Science, Engineering and Technology. 5 (18), 4563-4567.

[5] Karahan O. and Atis C.D. (2011) *"The durability properties of polypropylene fiber reinforced fly ash concrete."* Materials and Design, 32 (2), 1044-1049

[6] Kim S.B., Yi N.H., Kim H. Y., Kim J.H.J., and Song Y. C. (2010). *"Material and structural performance evaluation of recycled PET fiber reinforced concrete."* Cement and Concrete Composite, 32, 232-240.