International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:7, No:10, 2013

A Study on the Improvement of the Bond Performance of Polypropylene Macro Fiber According to Longitudinal Shape Change

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***Abstract*—**This study intends to improve the bond performance of the polypropylene fiber used as reinforcing fiber for concrete by changing its shape into double crimped type through the enhancement its fabrication process. The bond performance of such double crimped fiber is evaluated by applying the JCI SF-8 (dog-bone shape) testing method. The test results reveal that the double crimped fiber develops bond performance improved by more than 19% compared to the conventional crimped type fiber.

***Keywords*—**Bond, Polypropylene, Fiber reinforcement, Macro fiber, Shape change.

I. Introduction

FIBER REINFORCED CONCRETE (FRC) is a typical reinforcement method used to control cracking and improve the brittleness inducing failure of concrete subjected to tension and dynamic loading.

The types of fiber used as reinforcement of concrete are steel fiber (ST), nylon fiber (NY) and polypropylene (PP). Among them, even if PP fiber provides similar physical performances and cost competitiveness compared to the other types of fiber, its hydrophobicity degrading the bond performance at the fiber-cement paste interface restrains its applicability for reinforcement purpose. Several researchers implemented studies in order to overcome this problem [1] but most of them resulted in cost increase due to additional fabrication processes, which in turn made PP fiber lose its cost competitiveness. Therefore, this study intends to improve the bond performance with regard to its physical properties while preserving its remarkable cost competitiveness. To that goal, specimens made of mortar and PP fiber are fabricated and their performance is evaluated through the analysis of the bond performance.

II. Strengthening of the Bond Performance by Changing the Longitudinal Shape of the Fiber

In view of the basic tensile performance, fibers NY, ST and PP do not exhibit particular difference. Compared to the other types of fiber, the most peculiar drawback of PP fiber is its inherent hydrophobic property, which affects the bonding strength of the fiber with the cement paste. This hydrophobicity is known to degrade the bond performance by creating pores at the bond interface owing to the poor bond strength between the fiber and water during the mixing of the cement paste and fiber. As a solution to solve this problem, numerous studies examined the hydrophilization of PP fiber by chemical change and coating. However, such solution increases the fabrication cost of the fiber and appears thus to be inadequate. Accordingly, our research team proposes a method strengthening mechanically the bond performance by giving a double crimped shape to the fiber through up-down-rightward-leftward deformation so as to improve the bond performance in the fabrication process without cost increase.

Most of the fabrication process of the fiber is described in Fig. 1. The process follows the following successive steps: melting → cooling → pultrusion → longitudinal deformation → cutting.

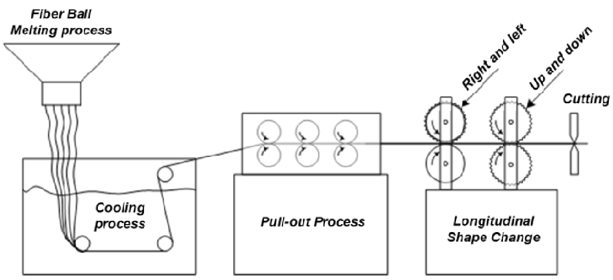

Fig. 1 Schematic fabrication process of the developed fiber

Moreover, since usual crimping is executed during the longitudinal deformation, most of the deformation of the longitudinal shape is performed at this stage [2], [3]. However, this study adds a double crimping apparatus (Fig. 2 (a)) so as to contribute to the improvement of the performance by achieving the 3D crimped shape shown in Fig. 3. This deformation does not require any additional process and necessitates only the fabrication of a form fitted to the intended shape and of a device executing the double crimping process within the common fabrication process of the fiber. Since the fabrication can be conducted through a method identical to the usual fabrication scheme after the installation of the device, the process becomes very efficient.

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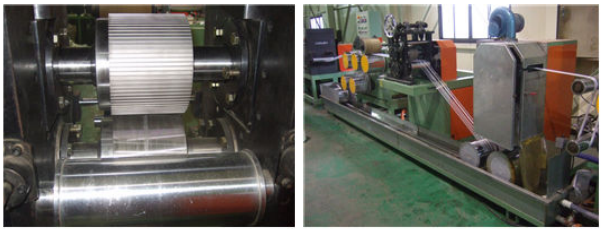
International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:7, No:10, 2013



(a) Power-driven press (b) Fabrication process of fiber

Fig. 2 Press casting process of fiber

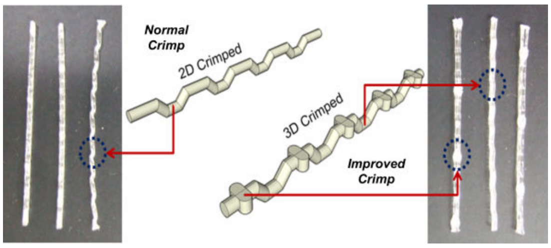
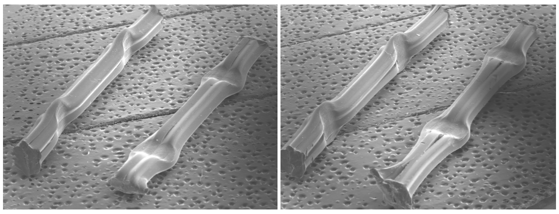
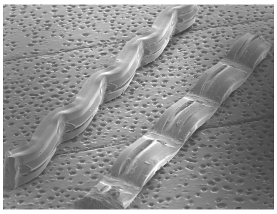


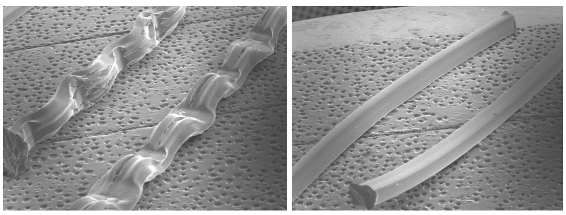
Fig. 3 PP fiber with strengthened bond performance fabricated by double crimping



Crimped A type (press depth: mid) Crimped A type (press depth: strong)



Crimped B type (heat treated during deformation)



Crimped AB type Straight

Fig. 4 Lateral SEM photographs of the developed PP fibers

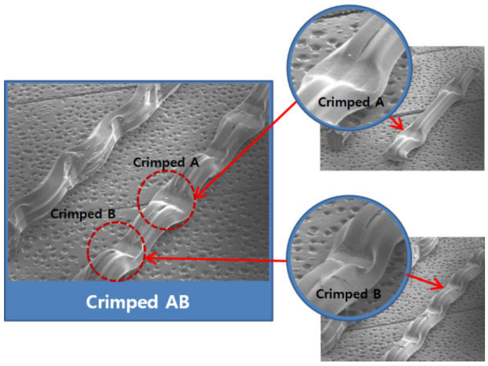


Fig. 5 Hybrid crimping of the developed PP fiber

Figs. 4 and 5 depict the photographs of the SEM imaging of the fiber. Different shapes can be observed according to the type of crimping (A, B, AB). Crimped A type was realized by a cylindrical pressing device fabricated for this purpose as shown in Fig. 2 (a). The pressing force was adjusted by tuning the depth of the cylinder (mid, strong). As shown in Fig. 4, the SEM image of the hybrid crimped AB fiber exhibits appropriate double crimped shape combining those of types A and B. This hybrid crimped type fiber is believed to provide outstanding bond performance owing to its upward-downward three-dimensional mechanical bonding effect.

III. Test Setup and Method

A. Test Setup

Table I arranges the test setup and mix proportions adopted in this study. First, cement mortar was fabricated with a C:S mix ratio of 1:1.7 and water-to-binder ratio of 50%. Single specimens were planned considering 6 test variables by embedding the straight, crimped A type, crimped B type, double crimped AB type combining the A and B types macro PP fibers in the mortar.

TABLE I
Mix Proportions of Mortar and Test Setup

Test variables				Test level
	W/C (%)		1	50
	Cement-sand ratio		1	1:1.7
Mix data	Crimped A	Press level	2	Strong, mid
	Crimped B	Fiber shape	1	Crimped type
	Crimped AB	Press level	2	Strong, mid
		Fiber shape	1	Double crimped type
	Straight	Fiber shape	1	Straight
Test data	Hardened mortar		1	Dog-bone pull-out test JCI-SF 8 (28 days)

B. Materials and Testing Method

The characteristics of the major materials adopted in this study are listed in Tables II to IV. The cement is an ordinary Portland cement (OPC) produced by the domestic company A. The aggregates are originated from Daeduk and Oksan in Korea.

TABLE II
PHYSICAL PROPERTIES OF ORDINARY PORTLAND CEMENT

Density (g/cm^3)	Blaine (cm^2/g)	Soundness (%)	Setting time (min)		Compressive strength (MPa)		
			Ini.	Fin.	3 dd	7 dd	28 dd
3.15	3.165	0.18	235	320	20.4	29.4	38.7

TABLE III
PHYSICAL PROPERTIES OF AGGREGATES

Type	Density (g/cm^3)	Finess modules	Absorption ratio (%)
River sand	2.65	2.86	2.63
Crushed sand	2.50	2.62	1.42

TABLE IV
PHYSICAL PROPERTIES OF FIBER

Density (g/cm^3)	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Elastic modulus (GPa)
0.91	40	0.90	562	8.5

The JCI-SF-8 dog-bone shape mold testing method proposed by JCI is adopted for the evaluation of the bond performance of the fibers in this study [4]. In Fig. 6, the fiber is anchored at 4 spots delimited by the partitioning board disposed at the center of the tensile test mold. An embedment length of 10mm was adopted for the fiber. After their fabrication, the bond test specimens were cured at 21±2°C and humidity of 60±2% during 24 hours before being stripped off the molds. The specimens were then subjected to water curing during 28 days. Three specimens were fabricated and tested for each test variable. The bond strength was computed after deriving (1) by means of the mean values.

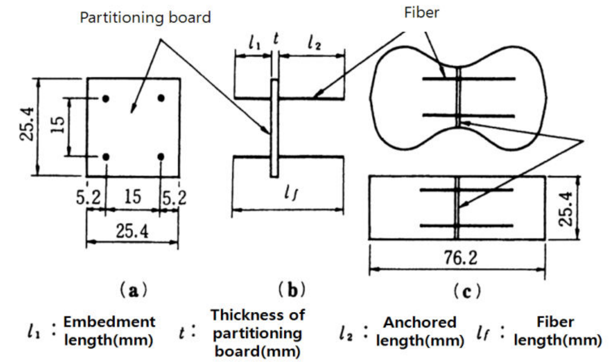


Fig. 6 Test method for the evaluation of the bond performance of fiber [4]

$$\tau_{\max} = \frac{P_{\max}}{2(b+h)l} \tag{1}$$

where τ_{max} = ultimate bond strength; P_{max} = ultimate bond load; b = width of fiber; h = thickness of fiber; and, l = length of fiber.

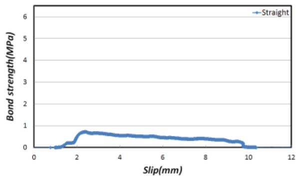
Fig. 7 Fabrication process of specimens

Fig. 8 JCI SF-8 dog-bone test of specimens

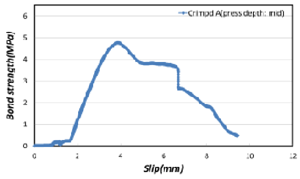
IV. TEST RESULTS AND DISCUSSION

Fig. 9 plots the slip-bond strength curves obtained for each test variable. First, the ultimate bond strength of the straight fiber remains below 1 MPa indicating very poor bond performance. The slip is also seen to occur continuously without resistance to the load, which also demonstrates its very poor bond performance.

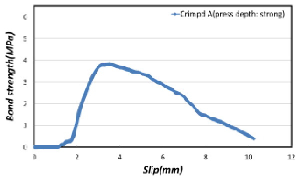
Crimped A type fiber fabricated by spreading the fiber laterally through the application of a constant pressure by the pressing device exhibits different slip shapes according to the degree of press (strong, mid). The specimen with mid press level develops an ultimate bond strength and mechanical bond performance superior to that of the specimen with strong press level. This specimen shows the presence of a section supporting the load at the pressed portion owing to the mechanical bond resulting from the deformation given by the press. Besides, the slip –bond strength of the crimped A type specimen with strong press level tends to experience continuous loss of its strength without definite supporting section. Such result can be verified through the extent of damage according to the press of crimped A type in the SEM image. The comparison of the specimens with mid press level to those with strong press level reveals that the specimens with mid press level exhibit smooth spreading as well as stable lateral spreading of the fiber. In the case of the specimens fabricated with strong press level, the inner side of the fiber connected to the pressed section of the fiber shows damage due to the excessive pressure exerted during the fabrication. Such damage of the connection prevents the fiber to develop fully its bond performance following the spreading of the pressed portion, and results in the degradation of the ultimate bond strength and the loss of mechanical bond performance during the slip. Consequently, the application of mid press depth appears to be adequate during the manufacture of crimped A type fiber. This level should prevent damage caused by the pressure applied to the fiber. In addition, since the appropriate level depends on the cross-sectional area of the fiber, further study should propose a press ratio with respect to the cross-sectional area of the fiber.



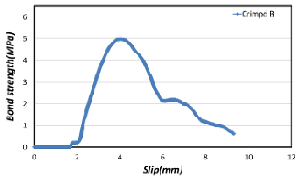
Straight



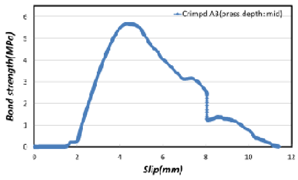
Crimped A type (press depth: mid)



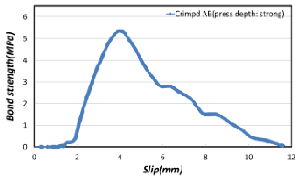
Crimped A type (press depth: strong)



Crimped B type



Crimped AB type (press depth: mid)



Crimped AB type (press depth: strong)

Fig. 9 Slip-bond strength curves per test variable

For the hybrid crimped AB type, since the shapes of crimped A and B types are appropriately combined as shown in the SEM image of Fig. 5, the corresponding slip-bond strength curve obtained from the test also indicates outstanding mechanical bond performance. Similar to the individual crimped A type, the mid press level also exhibits the best performance. The fabrication process of the hybrid crimped AB type being complex, the process could not be conducted under thermo-setting state by heat treatment. The settlement of this problem is expected to enhance further the bond performance of this hybrid crimped type.

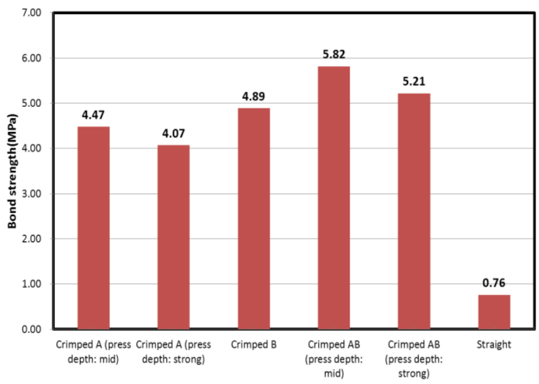


Fig. 10 Bond strength with respect to the shape of the fiber

Fig. 10 compares the bond strength of the fibers according to the shape. The conventional straight fiber is seen to develop the lowest bond strength with a value of 0.76 MPa. For crimped A type, better performance is provided with a mid press level. Outstanding bond strength is obtained with a mid press level for hybrid crimped AB type.

Consequently, crimped A type and crimped B type fibers exhibit bond performance superior to the straight fiber. Besides, the hybrid crimped AB type fiber develops remarkable bond strength of 5.8 MPa, which represents an improvement of the bond strength by more than 19% compared to the other fiber shapes. The achievement of studies dedicated to the analysis of the bond performance with respect to the ratio of the press level to the cross-sectional area of the fiber and to the heat treatment of crimped AB type during the manufacturing process will enable to fabricate fibers exhibiting further improvement of the bond performance.

V. Conclusions

In a will to improve the mechanical bond performance of the reinforcement fiber, this study produced double crimped fibers by enhancing the fabrication process of the fibers. The performance of the PP fiber was evaluated by conducting bond performance test on a mortar reinforced by the so-improved fiber. The following conclusions could be derived.

1) The ultimate bond strength of the straight fiber remained below 1 MPa indicating very poor bond performance. The slip was also seen to occur continuously without resistance to the load, which also demonstrated its very poor bond performance. Crimped A type fiber fabricated by spreading the fiber laterally through the application of a constant pressure by the pressing device exhibited different slip shapes according to the degree of press (strong, mid). The specimen with mid press level developed an ultimate bond strength and mechanical bond performance superior to that of the specimen with strong press level.
2) Crimped A type and crimped B type fibers exhibited bond performance superior to the straight fiber. Crimped AB type combining these two types of fibers developed remarkable bond strength of 5.8 MPa, which represented an improvement of the bond strength by more than 19% compared to the other fiber shapes.
3) The achievement of studies dedicated to the analysis of the bond performance with respect to the ratio of the press level to the cross-sectional area of the fiber and to the thermal treatment of crimped AB type during the manufacturing process will enable to fabricate fibers exhibiting further improvement of the bond performance.

Acknowledgment

This research was supported by a grant from a Strategic Research Project (Development of Fiber Reinforced Concrete Base for Composite Pavement System) funded by the Korea Institute of Construction Technology.

References

[1] Hyun-Do Yun et al., “Effect of Fluorination on Pullout Behavior of Polypropylene Fibers from Cementitious Matrix”, *Journal of the Korean Society of Civil Engineers*, 2006, pp.123-130.

[2] Jong-Pil Won et. al., “Optimum Geometry Factor of Structural Synthetic Fibers”, *Korea Concrete Institute*, Vol. 14 No. 4, 2002, pp. 474-482.
[3] P. Soroushian et al., “Fiber type effects on the performance of steel fiber reinforced concrete”, *ACI Materials journal*, 1991, pp.129-134.
[4] Committee on Fiber Reinforced Concrete, JCI-SF8: Method of Testing for Bonds of Fibers; *Japan Concrete Institute*: Tokyo, Japan, 1984.

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