FUNDAMENTAL STUDY ON STRENGTHENING EFFECT OF CONCRETE BEAMS STRENGTHENED WITH INTERNAL PBO FIBER MESHES

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1. INTRODUCTION

The fiber reinforced polymer, or FRP, systems have been widely used for strengthening existing reinforced concrete structures nowadays because they have shown an excellent performance in terms of tensile strength, modulus of elasticity and their light weight.

Among the advanced FRP materials, Polyparaphenylene Benzobis Oxazole (PBO) fiber mesh, as illustrated in Fig. 1, has been promoted as a new generation of super fiber with the high tensile strength, high elastic modulus and high fire/fuel resistance (Wu et al. (2003)).

In order to develop a new concrete structure by using PBO fiber meshes as a strengthening material inside a concrete structure, these elementary tests were carried out to investigate its mechanical characteristics as a fundamental study. Load-deflection curve, crack pattern and actual tensile strength were investigated in this study.

2. EXPERIMENTAL PROGRAM

(1) Specimen preparation and details

Figure 3 shows a general profile of all strengthened and unstrengthened specimens. Two unstrengthened specimens, which are Ref1 and Ref2, were set up to be the control specimens. S1 and S2 were strengthened with one layer internal PBO fiber meshes disposed along the bottom part of the specimens with 27.5 mm concrete cover. The PBO fiber meshes used in S2 were coated by epoxy resin before casting while the uncoated PBO fiber meshes were provided in S1. The coated PBO fiber meshes were also prepared for strengthening in S3 and S4, but the number of layer was increased to be two and three, respectively.

Total width of the PBO fiber meshes used in all strengthened specimens was 60 mm, therefore, there were 20 mm left in each side of the formwork for allowing aggregates to penetrate underneath the PBO fiber meshes as shown in Fig. 2.

All the specimens were demolded after 24 hours and cured with water-spray for 7 days before testing. Table 1 lists the details of self-compacting concrete mix proportion and the designed strength of concrete was 35 N/mm^2.

(2) Instrumentation and test procedures

The measurement of concrete strain and crack width was made by three electrical strain gauges and three π displacement transducers, attached to concrete surface of the specimens strengthened with internal PBO fiber meshes, as shown in Fig. 3. The load generated from the autograph machine was gradually applied to the specimen until the failure at the load rate of 0.1 mm/min according to ASTM C293/C293M (2010). The specimens were monitored in terms of applied load and mid-span deflection while the crack propagation on the side surface was recorded by taken pictures during the loading.

Fig. 1 PBO fiber meshes

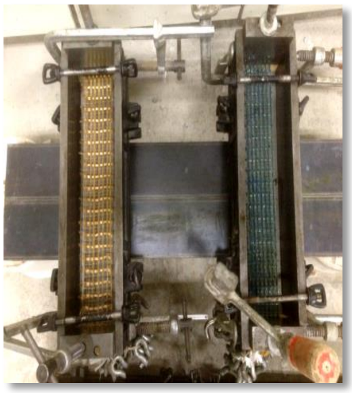

Fig. 2 Formwork preparation

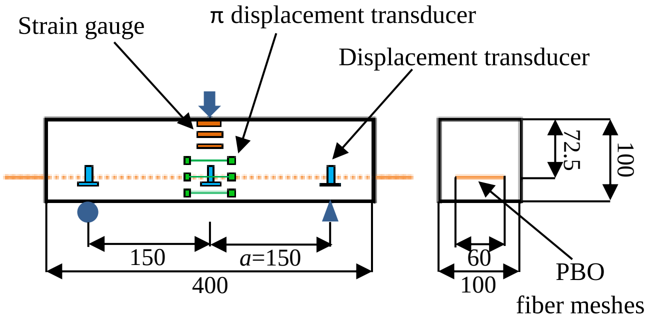

Fig. 3 Detail of specimens (unit: mm)

Table 1 Mix proportion of concrete

G_{max} (mm)	W/C	Unit weight (kg/ m^3)						
		W	C	LP	S	G	SP	V
15	0.6	175	292	249	718	857	8.12	0.35

W: Water, *C*: Cement, *LP*: Lime stone powder,
S: Fine aggregate, *G*: Coarse aggregate, *SP*: Superplasticizer,
V: Viscosity improver

Table 2 Summary of experimental results

Specimen designation	Layer of PBO mesh	f_c' (N/mm^2)	Load at flexure (kN)	Load at second peak (kN)
Ref1	-	36.33	11.04	-
Ref2	-	36.33	10.51	-
uncoated S1	1	36.33	11.85	7.56
coated S2	1	36.33	10.98	8.74
coated S3	2	39.45	10.37	16.74
coated S4	3	39.45	9.69	24.21

Keywords: PBO fiber mesh, Shear strengthening, Internal strengthening system
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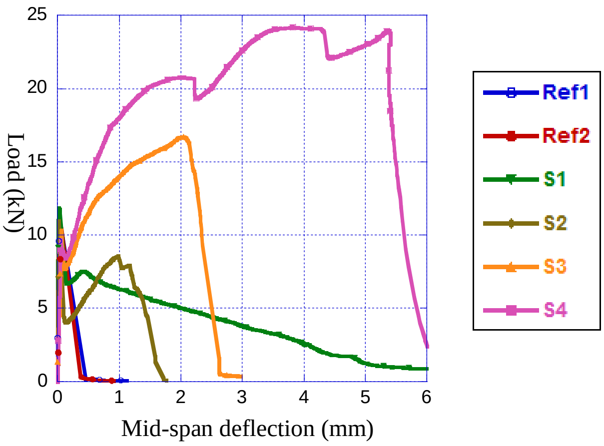

Fig. 4 Load-deflection curves

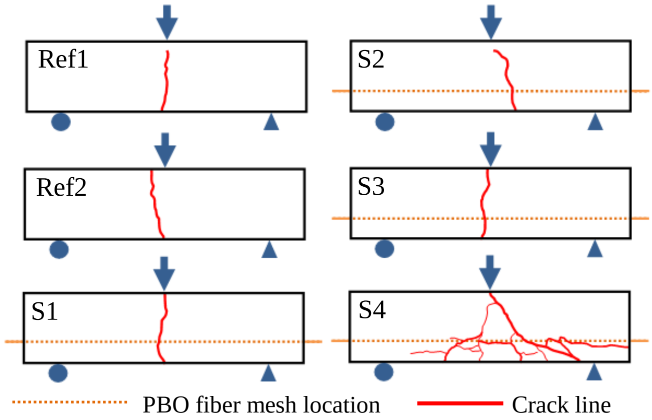

Fig. 5 Crack patterns

3. EXPERIMENTAL RESULTS

(1) Load-deflection relationship and failure mode

Experimental results and compressive strength of concrete in all specimens are listed in Table 2. Load-deflection relationship and the crack distribution of the specimens are shown in Fig. 4 and Fig. 5, respectively.

The loads of both two reference specimens linearly increased until reached their bending capacities which were 11.04 kN for Ref1 and 10.51 kN for Ref2. Then, the big flexural cracks happened and the load dropped to almost 0 kN. The failure mode of these reference specimens was the flexural failure.

For the strengthened specimens, the initial state of all specimens exhibited the same behavior in which the loads linearly increased until they reached their concrete bending capacities. Then, the loads of all strengthened specimens suddenly dropped because of the occurrence of a flexural crack at around the mid-span of the specimens. After that, the loads increased again because of the internal PBO fiber meshes.

For S1 specimen, the load reached the second peak load at 7.56 kN and decreased gradually with the increase in displacement. The failure mode of S1 was detachment of PBO fibers in the PBO fiber meshes.

For S2 specimen, the load increased again with the same behavior as S1 but a higher second peak load at 8.74 kN could be obtained. The failure mode of this specimen was a rupture of the PBO fiber meshes inside the concrete specimen.

The second peak load of S3 specimen increased almost twice as S2 at 16.74 kN and the failure mode of this specimen was still a rupture of the PBO fiber meshes.

In case of S4 specimen, after the load reached the bending capacity of the concrete at 9.69 kN, it dropped to 8.40 kN and a small flexural crack was observed in this state. Then, the flexural crack expanded and there were some cracks propagating along the mesh alignment in the longitudinal direction, however, the load of S4 specimen still increased continuously. Finally, a big diagonal crack occurred, as clearly shown in Fig. 5, and the load dropped rapidly. The second peak load of this specimen was 24.21 kN and the observed failure mode was a shear failure.

(2) Actual tensile strength of PBO fiber meshes

The tensile strength of the PBO fiber meshes measured by uniaxial tensile strength test from the manufacturer was 5800 N/mm^2 while the actual tensile strength of each specimen obtained from the experiments could be calculated from the following equation:

$$f_p = \frac{M}{AZ} \qquad (1)$$

in which f_p is the actual tensile strength of the PBO fiber meshes (N/mm^2), M is the bending moment of the specimen at the second peak load (N.mm), A is the cross section area of the PBO fiber meshes (mm^2), Z is the level arm (mm).

The actual tensile strength of the specimens calculated from Eq. (1) were 4911 N/mm^2 for S1, 5580 for S2, 5785 N/mm^2 for S3 and 6140 N/mm^2 for S4. The difference between the experimental values and the manufacturer's values were 15.3%, 3.79%, 0.26% and 5.86%, respectively.

4. CONCLUSIONS

(1) The internal PBO fiber meshes can enhance the performance of the concrete members after flexural crack occurs.

(2) Increasing the number of the PBO fiber mesh layer can increase the structural performance of the concrete member.

(3) The internal PBO fiber meshes can bring its performance as the same level as the uniaxial tensile behavior, indicating that sufficient strengthening effect can be obtained when it is used for strengthened bigger structural members.

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