# SHEAR BEHAVIOR OF UFC-RC HYBRID BEAMS WITH PBO AND STEEL FIBERS

Tokyo Institute of Technology, Student Member, ○Baasansuren TOGTOKHBAYAR
Nippon Concrete Industries Co., LTD, Member Kenji YAMAGISHI
Nippon Concrete Industries Co., LTD, Member Yuki YAMASHITA
Tokyo Institute of Technology, Fellow, Junichiro NIWA

## 1. INTRODUCTION

The use of the steel fiber in ultra high strength fiber reinforced concrete (UFC) can provide the possibility of corrosion. In order to decrease this possibility, this study proposes to use Poly Benzobis Ozaxole (PBO) fiber instead of steel fiber. PBO fiber has the high tensile strength, elastic modulus, and thermal stability. In the previous study, the RC beams attached with UFC two-sided panels with various lengths of the PBO fibers were examined.

In order to investigate the mechanical properties of UFC with PBO fibers and the shear behavior of the RC-UFC permanent formwork with PBO fiber, the material test of the notched beams and the 4-point bending test of the RC beam with UFC permanent formwork were conducted in this study.

## 2. EXPERIMENTAL PROGRAM

### (1) Material test

Compressive strength test, splitting cylinder test and three-point bending test of the notch beam were conducted to investigate the mechanical properties of UFC using PBO and steel fibers. **Table 1** shows the mix proportion and fresh property of the UFC. PBO and steel fibers with the same length of 15 mm have diameter of 0.23 mm and 0.20mm, respectively. The volume contents of PBO and steel fibers in UFC were 1.5 vol.%. Three-point bending tests of notched beams were carried out to estimate the tension softening curve of UFC according to JCI-S-002-2003 "Method of test for load-loading point displacement curves of fiber reinforced concrete by using notch beam test".

### (2) Beam test

The UFC-RC hybrid beams consisted of cast-in-place RC beams with UFC permanent formworks as shown in **Fig.1**. The detail of the beams was illustrated in **Fig.2** including the dimensions, reinforcing arrangements and positions of strain gages, transducers and PI gages. In this study, three UFC-RC hybrid beams were tested to investigate the shear behavior and the effect of interface differences with PBO and steel fibers. As illustrated in **Fig.2**, PI gages and concrete gages were attached on the interface of the RC and UFC formworks to measure the opening width. Displacement transducers were set at the mid-span. **Table 2** listed the parameters of the specimens.

The specimens were subjected to the four-point bending test with a simply-supported condition. The shear span to effective depth ratio is 3.0.

## 3. EXPERIMENTAL RESULTS

### (1) Mechanical properties of UFC

**Table 3** and **Fig.3** show the material test results and the tension softening curves of UFC, respectively. The post-cracking strength of UFC with PBO fibers was lower than that of the steel fibers as shown in **Fig.3**.

Table 1 Mix proportion and fresh property of UFC matrix

| Name | Unit weight (kg/m³) | | | | | Flow Value (mm) |
|---|---|---|---|---|---|---|
| | W | B | S | Admixture | | |
| | | | | SP | D | |
| PBO-1.5 | 195 | 1287 | 905 | 30.6 | 6.44 | 260×250 |
| FM-1.5 | 195 | 1287 | 905 | 32.1 | 6.44 | 310×305 |

*W*: Water, *B*: Premix Binder, *S*: Sand, *SP*: Superplasticizer, *D*: Defoamer

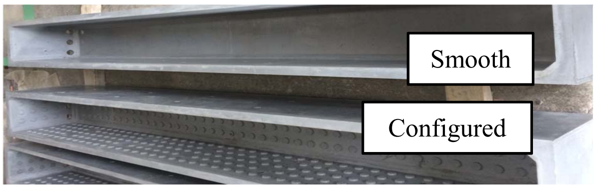


Fig.1 UFC permanent formwork

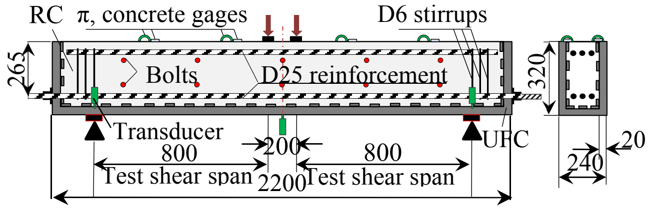


Fig.2 Detail of the specimen

Table 2 Specimen detail

| Name | UFC thickness (mm) | Fiber type | Interface surface |
|---|---|---|---|
| UFC_20_SM_PBO | 20 | PBO | Smooth |
| UFC_20_TP_PBO | 20 | PBO | Configured |
| UFC_20_TP_FM | 20 | Steel | Configured |

Table 3 Mechanical properties of UFC

| Name | $f_c$' (N/mm²) | $f_{cr}$ (N/mm²) | $E_c$ (kN/mm²) |
|---|---|---|---|
| PBO1.5% | 152 | 7.1 | 43.9 |
| FM1.5% | 178 | 8.2 | 43.8 |

$f_c$': Compressive strength, $f_{cr}$ : Cracking strength, $E_c$ : Young's Modulus

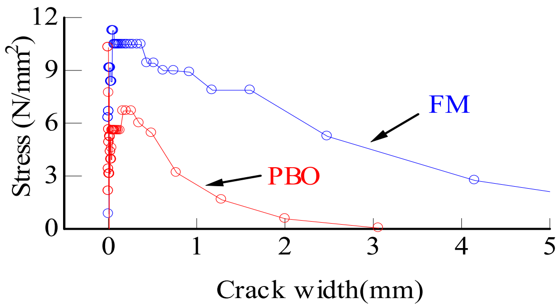


Fig.3 Tension softening curves

Key words: UFC, PBO fiber, Steel fiber, UFC formwork, Interface effect
Contact address: 2-12-1 M1-17 O-okayama, Meguro-ku, Tokyo, 152-8552, Tel: +81-3-5734-2584, Fax : +81-3-5734-3578

**(2) Shear force-displacement curves of UFC-RC hybrid beams**

Experimental results of shear capacity and compressive strength of concrete and UFC are listed in **Table 4**. Shear force-displacement relationships of the specimens are shown in **Fig.4.** In the case of the UFC_20_SM_PBO, the failure behavior could be divided into the certain stages. First stage, the flexural cracks initiated when the shear force reached to around 45 kN on the UFC surface at the mid-span. Second, diagonal crack occurred when the shear force reached around 105 kN on the UFC. After that, when the shear force increased until 118 kN, the stiffness reduced and the shear force decreased until 110 kN. Third, the activated PBO reinforcing fibers at the diagonal cracks increased the shear force until 115 kN as a peak force. At this stage, diagonal crack expanded due to the deformation of the beam and fibers were pulled out. After the second peak force, the shear force decreased gradually until 100 kN. In the case of the beam UFC_20_TP_PBO, the failure behavior during the first stage was almost same as that of UFC_20_SM_PBO. In the second stage, the diagonal crack observed on the surface when the shear force reached 120 kN. The diagonal crack expanded until 132 kN, after that the shear force stayed in constant due to the fiber bridging effect. Finally, the shear force reached at the peak 136 kN then the shear force decreased drastically. On the other hand, for the specimen UFC_20_TP_FM, when the shear force reached to the peak 197 kN, the shear force dropped slightly and kept constant due to the bridging effect of steel fiber. After that, the shear force dropped drastically.

**(3) Shear capacity of UFC**

The total shear capacity carried by UFC-RC beams is assumed to be divided into two parts. The first part is shear capacity provided by RC beam, the shear carried by RC beam can be obtained from **Eq. (1)** (Niwa et al., 1987), the second part is provided by the UFC panels.

$$V_{\text{total}} = V_{UFC} + V_c \tag{1}$$

$$V_c = 0.20 f_c'^{1/3} p_w^{1/3} \left(\frac{1000}{d}\right)^{1/4} \left(0.75 + \frac{1.4}{a/d}\right) b_w d \tag{2}$$

*Where:*

$V_{total}$: Total shear capacity (kN), $V_c$: shear capacity of RC beam without shear reinforcement (kN), $V_{UFC}$: shear capacity of UFC panels (kN), $f'_c$: compressive strength of concrete (N/mm$^2$), $p_w$: longitudinal reinforcement ratio (%), $d$: effective depth (mm)

According to the UFC guidelines, the shear capacity of UFC can be obtained by the following equations:

$$V_{UFC} = V_{rpc} + V_f \tag{3}$$

$$V_{rpc} = 0.18 f_c'^{1/2} \cdot b_w d \tag{4}$$

$$V_f = (f_v / \tan\beta_u) \cdot b_w z \tag{5}$$

*Where:*

$V_{UFC}$: shear capacity of UFC (kN), $V_{rpc}$: shear capacity provided by matrix (kN), $V_f$: shear capacity provided by reinforced fibers (kN), $f'_c$: compressive strength of UFC, (N/mm$^2$), $f_v$: average tensile strength perpendicular to diagonal cracks of UFC (N/mm$^2$), $b_w$: width of web (mm), $d$: effective depth (mm), $\beta_u$: an angle between member axis and a diagonal crack ($\beta_u$ is to be greater than 30 $^o$), $z$: distance from the location of compressive stress resultant to the centroid of the tension steel (mm)

In the above equations, it is clear that the effect of the interface differences cannot be considered. According to the calculation results, it was found that the shear capacity of UFC is highly related to the interface configuration.

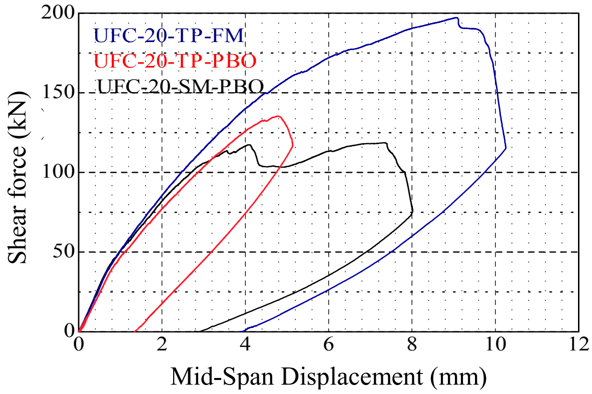


Fig.4 Shear force-displacement curve

Table 4. Test results

| Name | $V_{UFC}$ (kN) | $V_c$ (kN) | $V_{total}$ (kN) | $V_{exp}$ (kN) | $V_{total}/V_{exp}$ |
|---|---|---|---|---|---|
| UFC_20_SM_PBO | 113.0 | 76.0 | 189.0 | 118.6 | 1.7 |
| UFC_20_TP_PBO | 112.8 | 77.4 | 190.2 | 135.4 | 1.4 |
| UFC_20_TP_FM | 193.8 | 71.5 | 265.3 | 197.2 | 1.3 |

$V_{total}$: calculated shear capacity, $V_{exp}$: experimental shear capacity

**(4) Separation effect of UFC and RC**

For the specimen UFC_20_SM_PBO, the maximum separation width was 0.93mm. In the case of UFC_20_TP_PBO, the maximum separation width was 0.1mm. On the other hand, in the specimen UFC_20_TP_FM, the maximum separation width was around 0.52mm. Here, during the loading test, the bolts were released out to pretend the effect on separation width.

## 4. CONCLUSIONS

(1) The UFC using PBO fiber showed lower shear capacity than steel fiber.

(2) It is clarified that, the formwork configured interface highly affected on the shear capacity. The UFC using steel fiber with configured interface showed the highest shear capacity.

(3) UFC-RC separation width showed lower when the UFC formwork had configured interface.

## 5. REFERENCES

JSCE, "Recommendation for Design and Construction of Ultra-High Strength Fiber Reinforced Concrete Structures (draft)", JSCE Guidelines for Concrete, No. 9, Sep.2006.

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