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# FIBER ORIENTATION IN ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE AND ITS VISUALIZATION

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**Key words:** Ultra high performance fiber reinforced concrete, Fiber orientation, Visualization of fibers

**Abstract:** With the aim of investigating fiber orientation in ultra high performance fiber reinforced concrete (UHPFRC), a transparent model concrete containing fibers was placed in beam molds to visualize fiber orientation during placing. As a result, fibers were found to be obliquely oriented upward when the pouring position of concrete was fixed near one end of beam mold. Observation of cut planes of UHPFRC beam specimens also revealed that fibers were oriented similarly to those in visualization model concrete.

## 1 INTRODUCTION

Research into short fiber reinforced concrete (FRC) has a long history, including the recent development and practical use of strain hardening cement composites (SHCC) and ultra high performance fiber reinforced concrete (UHPFRC), which have been actively studied domestically and internationally. However, estimation of the dispersion and orientation of fibers in the matrix and their effect on the mechanical behavior of concrete have been recognized as key problems that have yet to be solved since the development of FRC. Major reasons for this are the difficulty of observing the dispersion and orientation of fibers within a concrete or mortar matrix and the current absence of technology to control their dispersion and orientation during placing.

With this as a background, this study attempted to visualize fibers in concrete specimens by modeling concrete using a transparent and viscous fluid. Also, hardened beam specimens made of UHPFRC were cut to observe fiber orientation for comparison with visualization test results. Flexural tests were conducted as well on specimens made of UHPFRC using synthetic fibers with different fiber orientations due to different filling methods, to investigate the effect of fiber orientation on the flexural behavior of specimens.

## 2 PRIOR STUDIES

In order to observe fiber orientation in concrete, it is simple and common practice to examine cut planes of specimens. Quantification of the state of fiber orientation has been under consideration recently by combination with image analysis techniques. Yokoo et al. [1] investigated the effect of specimen depth and placing direction on fiber orientation by image analysis of the cut planes of steel fiber UHPFRC specimens, as well as the relationship between fiber orientation and the mechanical properties by loading tests. Baba et al. [2] proposed a method of detecting synthetic fiber sections from the matrix by irradiating the cut plane with black light, as it is difficult to do so under visible light, and evaluated fiber orientation by image analysis based on this method.

Meanwhile, X-ray radiography, which allows direct observation of the inside without cutting specimens, has been used for steel fibers for a long time. Baba et al. [3] investigated methods of evaluating the state of steel fiber orientation in concrete through X-ray radiography. Schnell et al.[4] demonstrated 3D computer tomography method using X-ray was applicable for estimating fiber orientation in UHPFRC. However, X-ray radiography requires special equipment and qualified personnel, making the method not necessarily simple. Another problem is that it is inapplicable to synthetic fibers, which are radiolucent

Stahli et al., S.W.Kim et al, W. Pansuk et al. and M. Mohammed et al. [5-8] reported that the mechanical properties of UHPFRC vary depending on the fiber orientation based on loading tests on specimens fabricated by different filling methods or cut in different directions.

## 3 EXPERIMENTAL PROGRAM

### 3.1 Observation of fiber orientation in visualization model concrete

A colorless, transparent and viscous fluid obtained by adding water to high-absorbent polymer which was proposed by Hashimoto et al. [9], was used for the visualization models of fresh concrete. The fluid was prepared with an adjusted water to polymer ratio to attain a flow of around 200 mm without jigging. Even with the same flow value, this visualization model concrete may not precisely reproduce the behavior of actual UHPFRC, due to different densities and rheological properties. However, the authors considered that the model can reproduce the qualitative behavior of fiber orientation.

Two types of fibers were used for the tests: PVA fibers 0.66 mm in diameter and 15 mm in length and steel fibers 0.2 mm in diameter and 15 mm in length. To examine the effect of fiber content on the fiber orientation of the visualization model concrete, four levels of fiber content were adopted for PVA fibers: 0.5%, 1.0%, 2.0%, and 3.0%. In regard to steel fibers, a fiber content of 0.5% was adopted to facilitate the observation of fiber orientation, referring to the test results with PVA fibers to be described later in this paper.

A transparent acrylic container measuring 100×120×400 mm was used to assume mold for beam specimen. As to filling, two methods were applied as shown in Fig. 1: One is to fix the pouring position of concrete at one end of each mold to allow the concrete to flow along to the opposite end (hereafter referred to as “flow-filling”) and the other is to move the pouring position continuously in the longitudinal direction to level the concrete depth along the axis of the mold (hereafter referred to as “move-filling”).

The state of filling was recorded with a video camera for observation.

### 3.2 Observation of cut planes of steel fiber UHPFRC specimens

UHPFRC beam specimens containing steel fibers were cut to examine the sections, in order to confirm the fiber orientation behavior observed in visualization model concrete as stated above. Note that steel fibers were adopted because synthetic fibers are difficult to detect on the cut plane by the naked eye [2]. The UHPFRC used for these tests was a commercially available premixed type concrete. The materials and mix proportions were as specified by the manufacturer, containing 2 vol% steel fibers 0.2 mm in diameter and 15 mm in length. The flow without jigging was 275 mm at the time of filling. This mixture was placed by “flow-filling” in molds for beam specimens measuring 100×100×400 mm. After standard heat curing, a notch was cut in each specimen for three-point loading test. Broken pieces after loading test were cut with a concrete cutter to observe the state of fibers on the cut planes.

### 3.3 Flexural behavior of UHPFRC specimens made by different filling methods

As a result of visualization tests to be described in subsequent sections, fiber

**Table 1**: Mix proportion of synthetic fiber UHPFRC

| W/C (%) | Air (%) | Unit weight (kg/m$^3$) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | W | C | S | P | Ad | F1 | F2 |
| 18.0 | 5.0 | 175 | 1166 | 632 | 229 | 35 | 13 | 26 |

C:Silicafume cement, S: Silica sand, P: Silica powder, Ad : Superplasticizer, F1:PVAfiber (φ0.66×30mm), F2: PVAfiber (φ0.1×12mm)

orientation in beam specimens was found to vary depending on the filling method. It was therefore decided to investigate how the flexural behavior of UHPFRC changes with the filling method. The UHPFRC used for these tests, for which the authors developed the proportioning to be suitable for synthetic fiber UHPFRC, contained a combination of two types of PVA fibers. Note that a synthetic fiber UHPFRC was adopted for this experiment, as visualization tests showed that the qualitative behavior of fiber orientation is independent of the type and content of fibers. It was therefore considered that synthetic fiber UHPFRC would demonstrate a qualitative relationship between fiber orientation and flexural behavior of UHPFRC in general. Table 1 gives the materials and mix proportions of UHPFRC. Its flow with no jigging at the time of placement was 204 mm. The beams measuring 100×100×400 mm were filled by either flow- or move-filling method with UHPFRC of the same batch. The specimens were then air-cured at 20°C for 24 hours after placement, with the top surface being covered with plastic wrap. This was followed by steam curing at 90°C for 48 hours. After curing, a notch was cut in each specimen to be subjected to three-point bending test as shown in Fig. 2 to measure the load-crack mouth opening displacement (CMOD) curves.

Loading tests were conducted in accordance with JCI standard, "Test method for the load-displacement curve of fiber reinforced concrete using notched beams" [10], except that six specimens were used for each set of conditions.

A manual mechanical jack was used for loading. Load cells with a capacity of 100 kN and clip gauges with a sensitivity of 1/2000 mm were used for measuring the load and

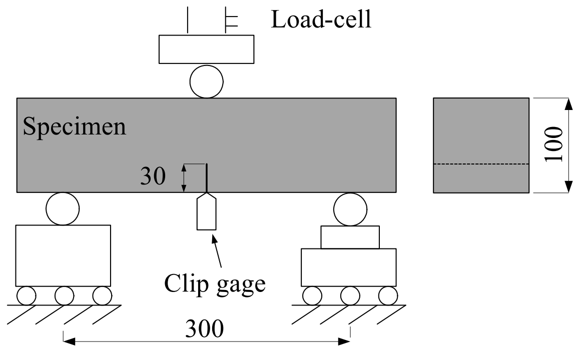



**Figure 2** : Three point bending test

CMOD, respectively.

## 4 TEST RESULTS

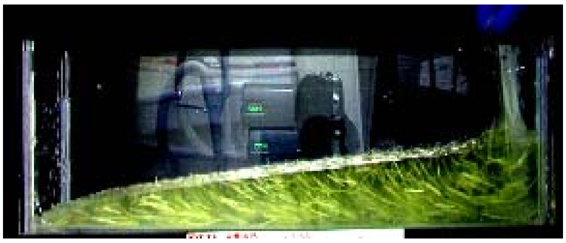
### 4.1 Observation of fiber orientation in visualization model concrete

Figure 3 shows the state of the flow of visualization model concrete containing 3% PVA fibers 0.66 mm in diameter and 15 mm in length. The flow with no jigging was 210 mm, with the fiber dispersion being quite satisfactory.

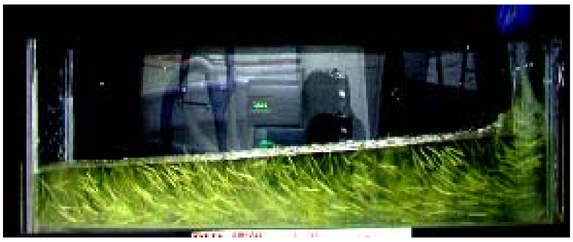
Figure 4 shows the state of flow-filling of visualization model concrete containing 0.5% PVA fibers 0.66 mm in diameter and 15 mm in length from the beginning to the end. As seen from Fig. 4 (a), fibers are horizontal at the tip of the flowing concrete and near the bottom of the mold but are inclined at the top surface near the pouring position. When the concrete stops moving forward as it reaches the other end of the mold (Fig. 4(b)), it begins to flow upward on the whole, orienting the fibers parabolically from the bottom forward and convex downward as shown in Fig. 4(d). Similar orientation behavior was observed with steel fibers as shown in Fig. 5.

Figures 6, 7, and 8 show the state of visualization model concretes respectively

**Figure 3**: Flow of visualization model concrete



(a) Reached at end of mold



(b) 50% of filling

(c) 80% of filling


(d) Completion of filling

**Figure 4**: Fiber orientation of PVA fiber (0.5%) by flow-filling

**Figure 5**: Fiber orientation of steel fiber (0.5%) by flow-filling

**Figure 6**: Fiber orientation of PVA fiber (1.0%)

**Figure 7**: Fiber orientation of PVA fiber (2.0%)

**Figure 8**: Fiber orientation of PVA fiber (3.0%)

containing 1%, 2%, and 3% PVA fibers 0.66 mm in diameter and 15 mm in length at the end of flow-filling. The fiber orientation becomes more difficult to recognize as the fiber content increases, but the parabolic orientation of fibers is similar to the case of 0.5%.

It has conventionally been considered that, when a mold for a beam specimen is flow-filled, concrete flows in the longitudinal direction and fibers are horizontally oriented. However, observation of visualization model concrete revealed that concrete flows upward from the bottom instead of in the longitudinal direction, orienting fibers nearly vertically instead of horizontally.

Accordingly, fibers in self-compacting-type UHPFRC are prone to be oriented in the direction of concrete flow. It is therefore inferred that fiber orientation in specimens directly depends on the concrete flow within the molds rather than such parameters as the type and content of fibers.

**Figure 9**: Fiber orientation of PVA fiber (0.5%) by move-filling

On the other hand, fibers in move-filled concrete were randomly oriented as shown in Fig. 9.

### 4.2 Observation of cut planes of steel fiber UHPFRC specimens

Figure 10 shows the appearance of a ruptured surface of a specimen after three-point loading test. Whereas fibers near the bottom of the mold are perpendicular to the ruptured surface (in the longitudinal direction of the mold), those near the mid-depth of the mold are at an oblique angle to the ruptured surface. Furthermore, fewer fibers are present in the area near the top surface.

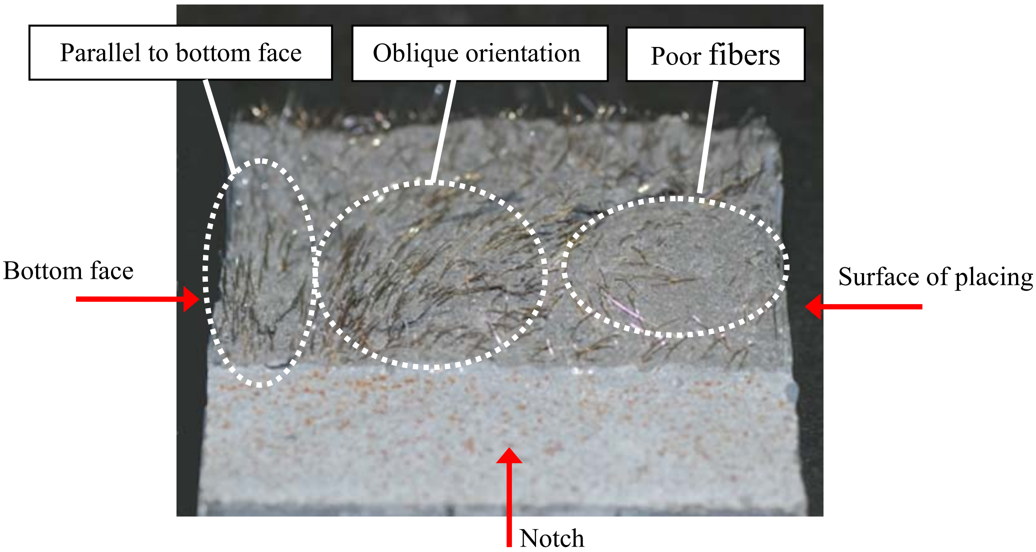



**Figure 10**: Ruptured surface of steel fiber UHPFRC

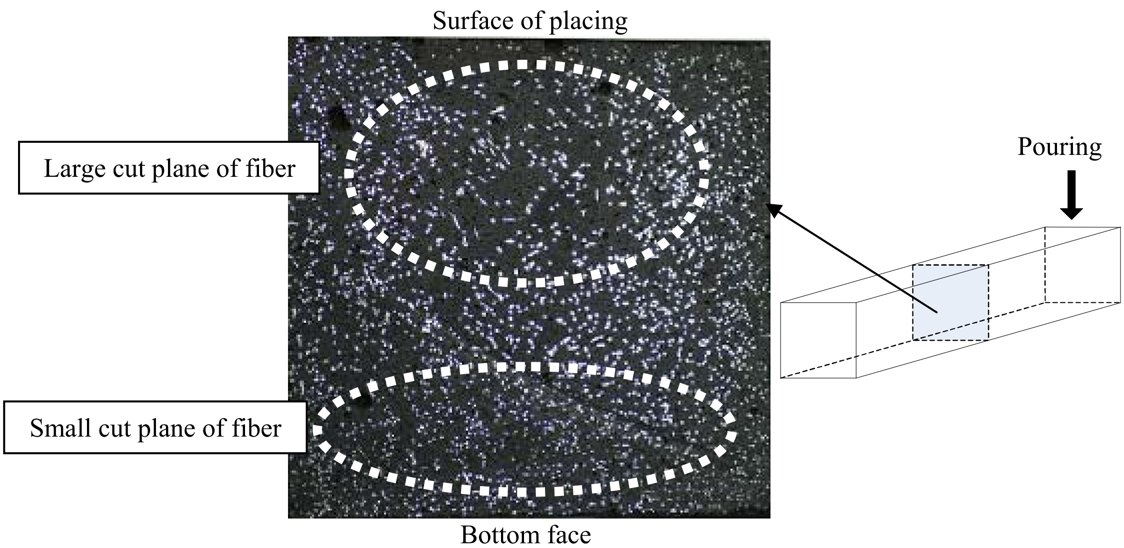
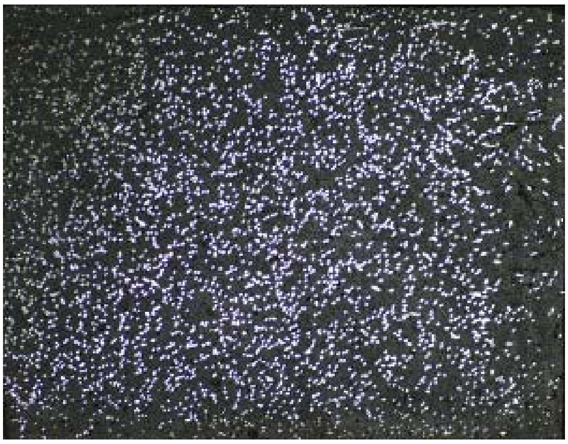
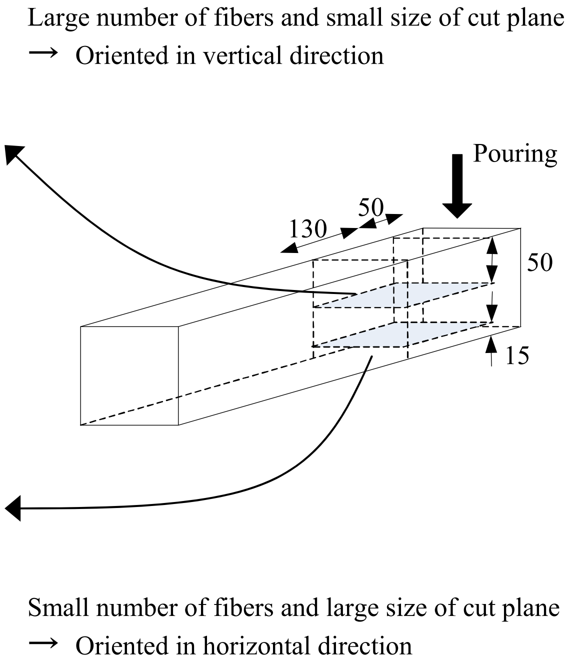
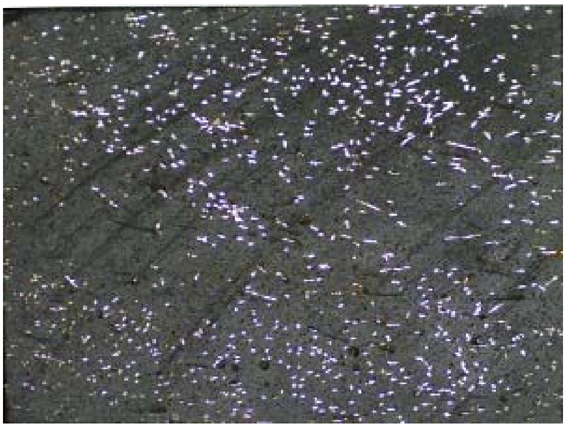



**Figure 11**: Vertical cut plane of steel fiber UHPFRC beam specimen



(a) Fiber orientaion in horizontal plane at middle height of specimen



(b) Fiber orientaion in horizontal plane near bottom surface

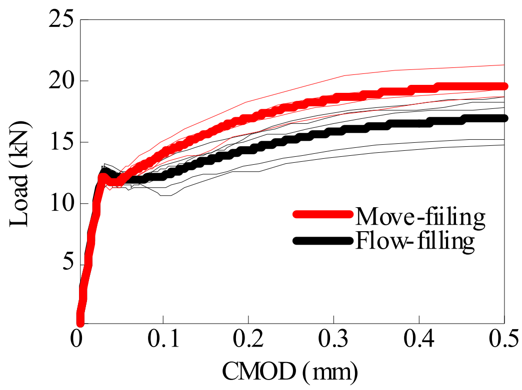
**Figure 12**: Horizontal cut planes of steel fiber UHPFRC beam specimen

Also, Fig. 11 shows a cross-sectional surface of a specimen. The white spots on the surface represent the cut planes of steel fibers. The areas of those near the bottom are small, demonstrating that the fibers are cut perpendicularly to their axes, whereas the areas of those in the upper part of the surface are large, suggesting that the fibers are obliquely oriented to the cut surface.

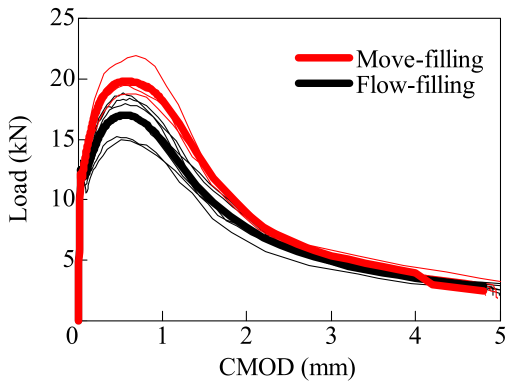
Figure 12 shows horizontally cut surfaces of a specimen. Figure 12(b) shows the level of 15 mm from the bottom with fewer fibers and longer sections, suggesting that fibers are oriented parallel to the bottom at this level. Figure 12(a) shows a horizontally cut surface at mid-depth, demonstrating the presence of fibers with a denseness similar to or greater than that of fibers on the vertical surface shown in Fig. 11. Moreover, many fibers are found with a small cross-section area. It is therefore inferred that fibers are obliquely standing as observed in visualization model concrete. Accordingly, the fiber orientation in actual steel fiber UHPFRC qualitatively agrees with that in visualization model concrete.

## 4.3 Flexural behavior of UHPFRC specimens made by different filling methods

As stated above, fibers tend to be oriented obliquely upward by flow-filling and randomly distributed by move-filling. In this light, three-point loading tests were conducted on notched beams of UHPFRC containing PVA fibers using beam specimens made by flow- and move-filling methods to examine the effect of fiber orientation on its flexural




(a) Initial part of curves




(b) Whole curves

**Figure 13**: Load-CMOD curves of beam specimens made by different filling methods

behavior.

Figure 13 shows the measured load-CMOD curves. Thick and thin lines represent the average curves and measurement data, respectively, of individual specimens. Though the cracking loads were similar regardless of the filling method, move-filling led to greater subsequent load gains, with the maximum load being 20% higher than that by flow-filling. This difference can be attributed to fiber orientation. When flow-filled, most fibers are oriented in a direction oblique or parallel to the rupture plane as shown in Fig. 10. This prevents full development of the bridging capability of fibers when compared with the random distribution of fibers resulting from move-filling. Note that the compressive strength of this UFC was 150 N/mm$^2$.

## 5 CONCLUSIONS

The results obtained from this study include the following:

(1) Fiber orientation in beam specimens was observed using visualization model concrete made of high absorption polymer. When the concrete was poured from one end of a beam mold, fibers were found to be oriented obliquely upward instead of horizontal in the longitudinal direction.

(2) Fiber orientation was observed by cutting UHPFRC beam specimens containing steel fibers. As a result, the tendencies of fiber orientation were found to qualitatively agree with those of visualization model concrete.

(3) Notched beams having different fiber orientations due to different filling methods were subjected to bending tests. The different filling methods that caused different fiber orientations led to a difference in the maximum load of approximately 20%.

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