# FATIGUE FLEXURAL TEST OF UHPFRC BEAM AIMING AT THE MATERIAL TENSILE BEHAVIOR CHARACTERIZATIONS

Faculty of Engineering, Hokkaido University Member ○Pengru Deng
School of Engineering, Hokkaido University Student Member Asyraf Khan
Graduate School of Engineering, Hokkaido University Student Member Junya Kuwagaki
Faculty of Engineering, Hokkaido University Member Takashi Matsumoto
Japan Construction Method and Machinery Research Institute Member Shinpei Kikuchi

## 1. INTRODUCTION

UHPFRC (Ultra-high Performance Fiber Reinforced Concrete) is a super dense cement-based composite material with excellent mechanical properties as well as superior resistance to environmental attacks. However, material models representing the fatigue behaviors especially under tension are not available so far. Therefore, aiming at elucidating the material tensile characterizations, static and fatigue flexural tests are conducted on UHPFRC beams instead of uniaxial tensile test considering the implementation difficulty and result stability of both testing methods.

## 2. EXPERIMENTAL PROGRAM

Static and fatigue 4-point flexural tests were conducted on UHPFRC beams as shown in **Fig. 1**. Besides, uniaxial compression tests were conducted on standard 50 (R) × 100 (H) mm of cylinder specimens. The material was provided by the Sunbridge Corporation. The J-THICOM association has presented the material basic information. In this study, the specimens were fabricated in a sequence of casting, spraying water, coving with a plastic sheet for one day, and moving into a 20℃ of water for curing until the testing day. The tests started at 28 days to circumvent the effect of curing age.

In accordance with the JIS Standards, the uniaxial compression tests were conducted under a load-controlled condition with a speed of 0.25 MPa/s. Two couples of strain gauges along the axial and hoop directions were attached at the center of both sides of the cylinder specimens to measure both elastic modulus and Poisson's ratio.

The displacement-controlled flexural static test was performed at a speed of 0.1 mm/min according to the JCI standard. Considering that the flexural strength may be affected by a strain rate effect, flexural tests were also conducted under 400 mm/min and 60 mm/min of speeds which are corresponding to 20 Hz and 3 Hz of fatigue loading frequencies, respectively. In terms of the fatigue flexural, load-controlled tests were performed on the specimens under a 3 Hz sinusoidal cyclic loading as this frequency is close to that on real bridge decks. The fatigue loading ranges were determined proportional to the static flexural capacity. The ratio of the lower limit was set equal to 0.2 for all specimens. The static and fatigue flexural tests employed a same data acquisition system as shown in **Fig. 1** except that the behavior in the tension side was recorded by a 100 mm of PI gauge in the fatigue tests whereas a 30 mm of strain gauge in the static tests. Consequently, one can obtain the midspan deflection evolutions excluding the influence from the possible rigid movement at the supports as well as the deformation evolutions on both the upper and lower faces in a certain range at the midspan.

In additions, to investigate the effects of the curing age, the uniaxial compression tests and the quasi-static flexural tests were conducted before (28 days), during (90 days), and after (165 days) the fatigue tests as shown in **Table 1** and **Fig. 2**.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Uniaxial compression test

The compressive strength ($f_c$) and elastic modulus ($E_c$) of UHPFRC at the employed three curing ages are summarized in **Table 1**. It is found that both $f_c$ and $E_c$ may not possess a monotonic relationship with the curing age. Thus, it may be stated that the compressive behaviors of UHPFRC may have entered a steady state during the fatigue tests.

### 3.2 Static flexural test

The static flexural loads of the UHPFRC beams under the three employed loading speeds at different ages are summarized in **Fig. 2**. In addition, the UHPFRC beams which could sustain the run-out number of cycles, i.e. 2,000,000, were tested under static loading after the fatigue test as well obtaining the ultimate flexural loads as shown in **Fig. 2**. In terms of the results of 0.1 mm/min of tests at different curing ages, it is found that the averaged ultimate load capacity exhibits a monotonic increase with the lengthening curing age from 7.34 kN at 28 days, to 7.69 kN at 90 days, and to 8.32 kN at 165 days. In addition, from the circled data points circle, the hardening effect due to a high strain rate can be clearly observed. More specifically, the average load capacities were 7.34 kN, 9.32 kN, and 8.49 kN under the loading speeds 0.1 mm/min, 60 mm/min, and 400 mm/min. As the load capacity is affected by other factors, such as fiber distribution content, the strain rate effect may not be the dominant factor for an about 7 times of loading speed increasing from 60 mm/min to 200 mm/min. Hence, for this variation of loading speed, a contradictory trend was observed. Actually, according to the general knowledge about the strain rate effect on cement-based materials, the three loading speeds may be divided into two groups,

Keywords: UHPFRC, J-THIFCOM, Fatigue, 4-point bending, Strain rate effect
Contact address: Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan, Tel: +81-11-706-6172

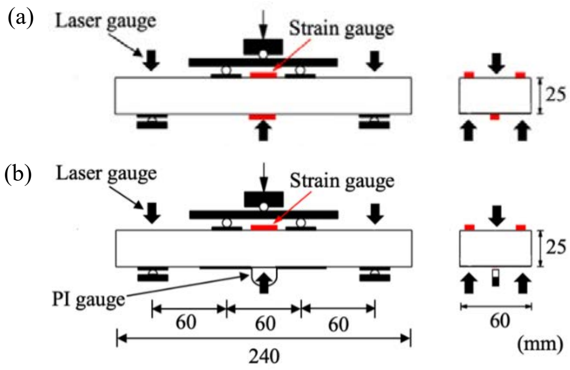


**Fig. 1** Experiment setup, a) fatigue, b) static

**Table 1** Compression test results

| Age (days) | Specimen number | $f_c$ (MPa) Each | $f_c$ (MPa) Ave. | $E_c$ (GPa) Each | $E_c$ (GPa) Ave. |
|---|---|---|---|---|---|
| 28 | CB28-1 | 165.40 | 152.03 | 38.70 | 38.97 |
| | CB28-2 | 137.30 | | 39.00 | |
| | CB28-3 | 153.40 | | 39.20 | |
| 90 | CB90-1 | 156.30 | 168.70 | 39.80 | 39.27 |
| | CB90-2 | 176.90 | | 39.30 | |
| | CB90-3 | 172.90 | | 38.70 | |
| 165 | CB165-1 | 170.95 | 145.66 | 37.56 | 38.22 |
| | CB165-2 | 126.82 | | 38.90 | |
| | CB165-3 | 139.22 | | 38.21 | |

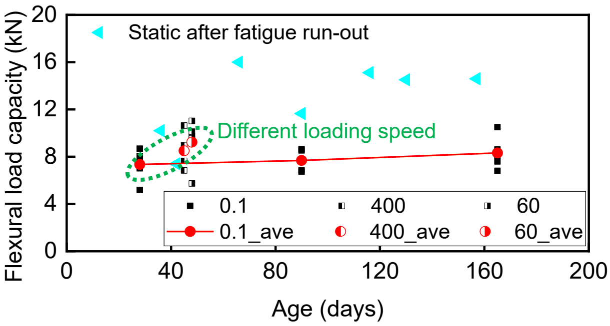


**Fig. 2** Static flexural test results

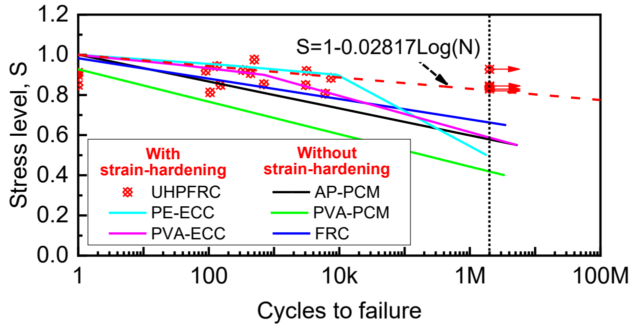


**Fig. 3** Fatigue stress vs. life relationships

i.e. quasi-static (0.1 mm/min) and quasi-dynamic (60 mm/min and 400 mm/min). As a result, it is reasonable to state that a higher loading speed generate a higher flexural load capacity. Besides, it is found that the run-out specimens exhibit relatively higher strengths, which may explain why they successfully sustained the 2 million cycles without failure. To figure out the reasons of these high strengths, more investigations may be required.

### 3.3 Fatigue flexural test

The flexural fatigue life of the UHPFRC beams as well as the linear fitting curve are shown in **Fig. 3** in comparison with the flexural fatigue stress to life (S-N) relationships of fibers reinforced concretes without strain hardening domain (AP-PCM, PVA-PCM, FRC) and with strain hardening domain (PE-ECC and PVA-ECC) as reported by Suthiwarapirak et. al. (2004). The flexural stress was calculated based on the elastic flexural beam formulation using the fatigue loads and measured specimen dimensions. The horizontal arrows indicate the specimens reaching the assumed fatigue endurance limit. It is noted that the S-N relationship of UHPFRC can be represented by a typical linear curve on a semi-log plot unlike ECCs. Compared to the other materials, UHPFRC exhibited a much lower degradation speed and a higher fatigue endurance limit which may be over 0.75 or even 0.8. However, unfortunately, the fatigue life of UHPFRC exhibited a large variation even if a relative stable four-point bending test method was employed. Therefore, it may be stated that the UHFPRC possesses a better durability, nevertheless, more efforts are needed to elucidate the deterioration and failure mechanisms of UHPFRC from the levels ranging from micromechanics to macro behaviors. As a further step, a more confident and reliable engineering application can be achieved with a deeper understanding of UHPFRC.

## 4. CONCLUSIONS

The flexural behaviors of the UHPFRC were investigated by four-point tests under both static and fatigue loading. In static tests, an apparent hardening effect due to high strain rate was observed, which may be induced by a relative long resetting time related to the high strength as well as deformation capability. Hence, the fatigue loading frequency range (< 15 Hz) which was accepted to have negligible effects on fatigue behaviors of cement-based material may be reconsidered for the tests on UHPFRC and the loading frequency should be selected carefully. Besides, the test results at different ages verified that the UHPFRC may achieve flexural strength for a long period. In fatigue test, a linear S-N relation of UHPFRC was observed on a semi-log scale. In addition, it was verified that compared with other existing fiber reinforced composites the UHPFRC may possess a much better durability manifested by an over 0.75 or even 0.8 of endurance limit.

## REFERENCES

Suthiwarapirak, P., Matsumoto, T., and Kanda, T.: Multiple cracking and fiber bridging characteristics of engineered cementitious composites under fatigue flexure, Journal of Materials in Civil Engineering, ASCE, 16(5), 2004, pp. 433-443.

## ACKNOWLEDGEMENT

Thanks to the financial supports from Kajima International Joint Research 2020, Grant-in-Aid for Early-Career Scientists (20K14808), as well as J-THICOM association for providing the specimens and technical assistance.