

CRACK CHARACTERISTICS OF THIN PLATE SHCC WITH PVA FIBERS

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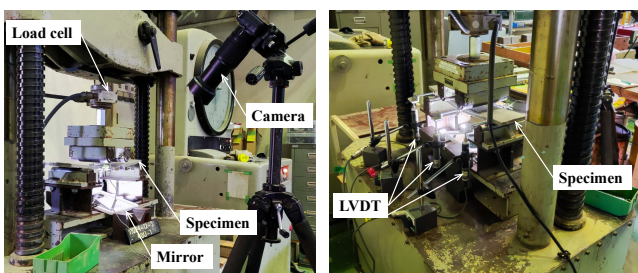
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1. INTRODUCTION

For strain-hardening cementitious composite (SHCC) exhibiting multiple-cracking behavior and high deformation capacity at the ultimate stage, crack characteristics—including crack number, crack width, and crack spacing—are the key indicators for evaluating their tensile performance. Consequently, accurate determination of the tensile stress and the corresponding tensile strain at the ultimate stage is essential for the reliable assessment of the deformation capacity of SHCC.

2. EXPERIMENT OVERVIEW

This study investigates the cracking characteristics of thin plates of SHCCs subjected to four-point bending test previously reported in the authors' study [1]. Although this may be repetitive, an overview of the experiment is described below. The mechanical properties of fibers used in this experiment are shown in Table 1. Ten specimens, which dimensions of 400mm long, 100mm wide, and 10mm thick, were prepared for each series of SHCC. The volume fraction for 100 μ m-diameter PVA fiber type was set to 3%, while those of 27 μ m and 40 μ m-diameter fiber were set to 2%. Four-point bending test was applied and Fig. 1 shows the loading set-up. Before loading, three red lines were drawn on 100 mm \times 100 mm pure bending area of bottom surface at 15 mm, 50 mm, and 75 mm distance respectively from the side as shown in Fig. 2. The red line of 75 mm from the edge would gradually disappear in digital camera vision field during loading because of the vertical displacement of specimen, the remaining two red lines were used to identify the crack width and crack spacing where they intersect. The digital camera was set in front of the loading stand to take photos for an interval of every 5 seconds and kept the shooting angle unchanged during the experiment. To allow the digital camera to capture the crack developments in the target area on the bottom side of the specimen, a mirror was set directly beneath the specimen. Three linear variable displacement transducers (LVDTs) are set at mid-span and the supports to measure the deflections. The crack patterns and load-mid-span deflection relationships are reported in [1].



(a) Front view (b) Back view

Fig. 1 Loading set-up

Table 1 Mechanical properties of fiber

| Series | Diameter (μ m) | Length (mm) | Tensile strength (MPa) | Elastic modulus (GPa) |
|-----------|---------------------|-------------|------------------------|-----------------------|
| PVA027-2% | 27 | 6 | 1800 | 46 |
| PVA040-2% | 40 | 12 | 1560 | 41 |
| PVA100-3% | 100 | 12 | 1200 | 28 |

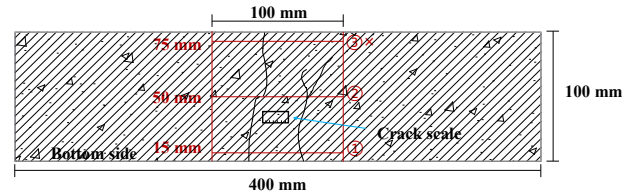


Fig. 2 Gauge area and pre-processed of the specimen

3. IMAGE PROCESSING PROCEDURE

An image processing measurement was adopted to identify and obtain statistical data of crack widths and crack spacings. An open-source image processing software commonly used in the biological research field named *ImageJ*, is adopted to process the selected photos of each stage. The image processing steps are as follows: First, the selected photos of each stage were converted from RGB format to grayscale. Then, the threshold of black and white was adjusted to a suitable value to show all the crack characteristics and binarize the grayscale image into only contained black and white pixels. Next, set the target length of the red line drawn in the experiment preparation to a scale of 100 mm. Finally, use the "Measure" function of the software to measure the pixels crossing crack widths and the crack spacings of selected photos within the former setting scale.

4. STATISTICS AND DISTRIBUTION

The objective of this study is to investigate the crack characteristics of each series of specimens at each stage. The crack widths for each specimen series at the ultimate stage were categorized into bins of 0.04 mm, and histograms at the ultimate stage were illustrated as shown in Fig. 3. Similarly, the crack spacing data at the ultimate stage were categorized into bins of 2 mm, with the corresponding histograms illustrated in Fig. 4. The probability density of crack widths and crack spacings of each specimen series was calculated according to Eq. (1).

$$P_i = \frac{f_i}{N \times \text{Bin}} \quad \text{Eq. (1)}$$

P_i : Probability density of Bin i

f_i : Frequency of Bin i

Bin: 0.04 mm or 2 mm

N : Total sample size.

Both normal and log-normal distributions were applied to describe the experiment data. The fitting results indicated that the log-normal distribution provided a superior representation

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of the experimental data for both crack width and crack spacing, consistent with the right-skewed characteristics of distribution.

As shown in Fig. 5a, during the max. load stage, the average numbers of cracks for the PVA027-2% and PVA040-2% series remained nearly constant at approximately 30, which were approximately twice that of the PVA100-3% specimens. Regarding the average crack width (Fig. 5b), the PVA027-2% and PVA040-2% specimens showed similar values, but these were significantly smaller than those of the PVA100-3% specimens, indicating a tendency that the crack widths increase as the increase of fiber diameters. In terms of crack spacing (Fig. 5c), the PVA027-2% and PVA040-2% specimens again showed similar behavior, with average values considerably smaller than those of the PVA100-3% series.

The qualitative tendencies observed at the ultimate stage were generally consistent with those at the max. load stage. Compared with the max. load stage, the average number of cracks at the ultimate stage slightly increased for all series, indicating that new cracks continued to open beyond the max. load stage. This finding suggests that defining the max. load stage and the corresponding deflection as the end of the strain-hardening or deflection-hardening stage may underestimate the real cracking capacity of this material. Furthermore, compared with the max. load stage, the average crack widths of the PVA027-2% and PVA040-2% specimens remained

nearly unchanged at the ultimate stage, whereas those of the PVA100-3% specimens increased more slightly. The average crack spacings slightly decreased for PVA027-2% and PVA040-2% series from the max. load stage to the ultimate stage, leading to a conclusion of average crack widths that the additional formation of new cracks and widening of existing crack widths within the same gauge length would lead to narrower crack spacings.

5. CONCLUSIONS

This study investigated the cracking characteristics of SHCC thin plate specimens using different dimensions of PVA fibers. Statistical fittings were employed to quantitatively analyze the mathematical distributions of crack widths and crack spacings after the image processing. The results showed that:

- 1) The log-normal distribution showed better fitting results with the statistical data of crack widths and crack spacings than normal distribution.
- 2) The average crack widths and average crack spacings showed increasing tendency as the increase of the fiber diameter.

REFERENCES

[1] Zhang H., Kanakubo T.: Bending Test of Polyvinyl Alcohol Fiber-Reinforced Cementitious Composite Plates, JSCE 2025 Annual Meeting, 12PM2-Oe-04.

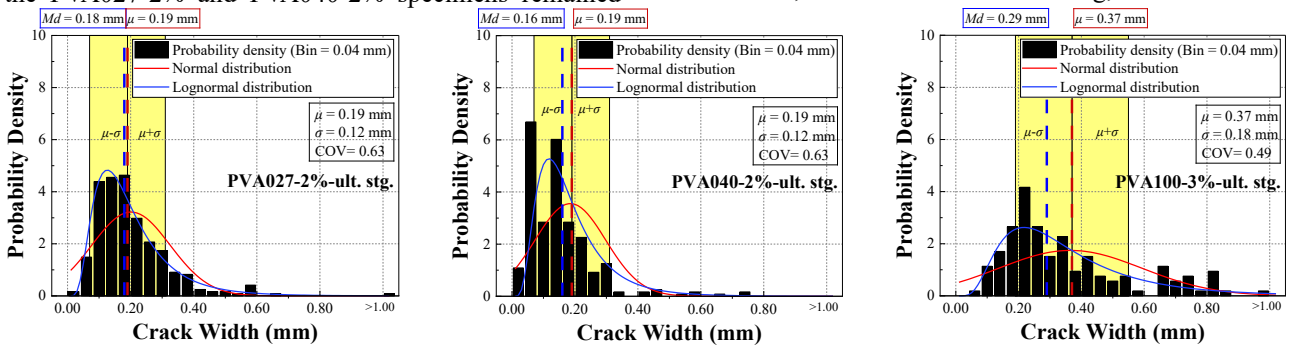


Fig. 3 Distribution of crack widths (*Bin* = 0.04 mm)

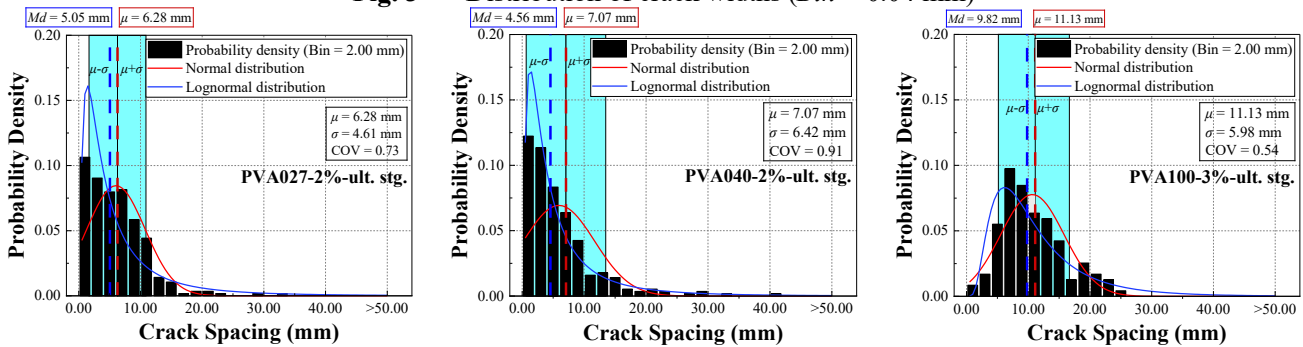


Fig. 4 Distribution of crack spacings (*Bin* = 2.0 mm)

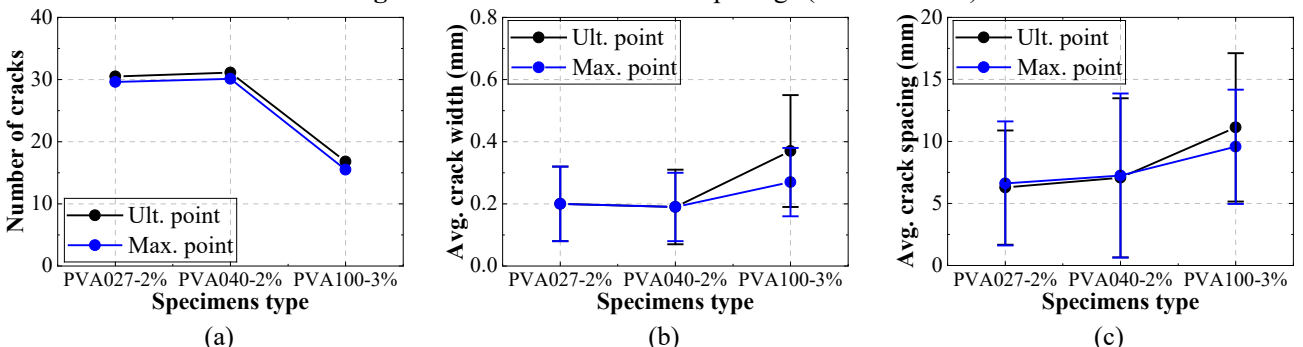


Fig. 5 Average value of crack characteristics at max. stage and ultimate stage