EXPERIMENTAL VALIDATION IN THE EFFECT OF SECONDARY FLEXURE IN UNIAXIAL TENSION OF CONCRETE

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ABSTRACT

There are still misunderstandings and arguments about the test method in uniaxial tension of concrete. One big argument is whether secondary flexure should be eliminated or not. In order to clarify this point, two treatments of secondary flexure were studied in the same experiment. In one treatment, secondary flexure is eliminated completely and in the other it is left to develop freely. Clear differences between both treatments were validated concerning load-deformation curves, tensile strength values and fracture energy values. It was concluded that secondary flexure should be eliminated in uniaxial tension test of concrete.

1 INTRODUCTION

In order to obtain tension softening behavior of concrete, uniaxial tension is the most promising way, because it provides both tensile strength and tension softening curve from an identical specimen. However, there are still misunderstandings and arguments about the test procedures. One big argument is concerning secondary flexure (e.g. van Mier [1]). Secondary flexure usually occurs because of heterogeneity of concrete even when load eccentricity is avoided completely. The secondary flexure is produced by local arrests of crack propagation by aggregates and prevents a symmetrical development of crack. It generates a strain gradient along the cross section and prevents a direct calculation of stress and deformation.

In uniaxial tension test, it is essential that tensile stress or cohesive stress is calculated by dividing the applied load by section area or ligament section area. The average COD (crack opening displacement) is also calculated in the ligament area by subtracting elastic deformation from the average deformation within the measuring length. Both calculations require that strain or stress distributions in the ligament area are almost uniform. Unless these requirements are fulfilled, an inverse analysis is necessary to obtain cohesive stress and COD. The principal value of uniaxial tension test is the capability to obtain directly both stress and COD without adopting an inverse analysis.

In this paper, it is discussed whether secondary flexure should be prevented or not, referring to experimental results. Both experiments when secondary flexure is eliminated completely and left to develop freely are performed and compared for that purpose.

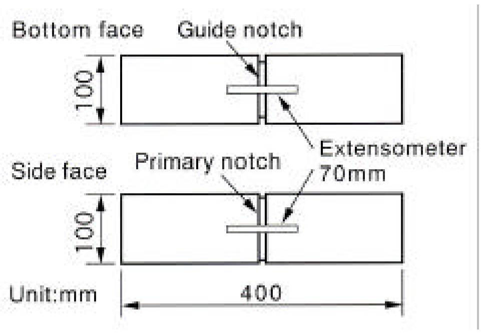

Fig. 1 Adopted specimen

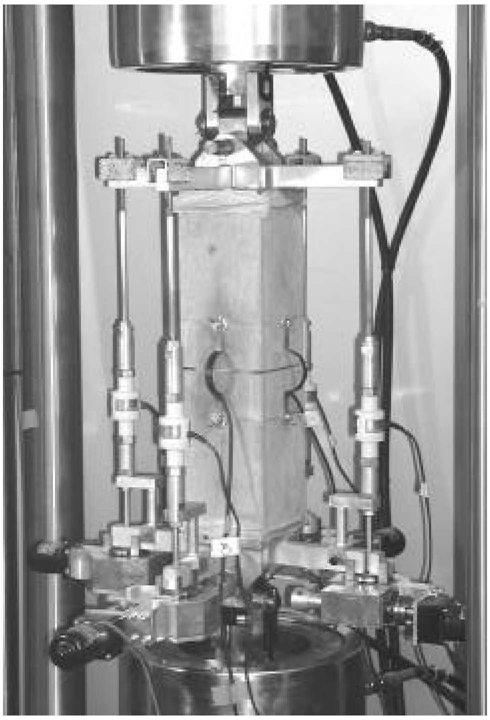
Fig. 2 Experimental set-up

2 EXPERIMENTAL PROCEDURE

Fig. 1 shows the prismatic specimen of 100x100x400mm with notches on all four side faces. It was already reported by Akita et al. [2] that a notched specimen gave exact tensile strength despite the appearance of stress concentration in the elastic region. Fig. 2 shows the experimental set up. In this figure, there can be seen the notched prismatic specimen, Ω type extensometer, load cells connected to steel rods, the boxes with DC motor accommodating the adjusting gear and tensile loading attachments of a loading machine. A 70-mm extensometer was attached on all four side faces aligning at the center. Four deformations obtained from the extensometers were used for both the elimination of the secondary flexure during the test and the acquisition of load-deformation curves. The average of the four deformations is applied to load control by a closed-loop loading machine. The gear system works to eliminate both the secondary flexure and the flexure caused by load eccentricity. This elimination was executed in such a way that the more elongated side was given sufficient contraction to reach a proper balance by tightening the concerned adjusting gear system during the test. Secondary flexure can be completely eliminated using this apparatus and also can be left to develop freely without operating this apparatus.

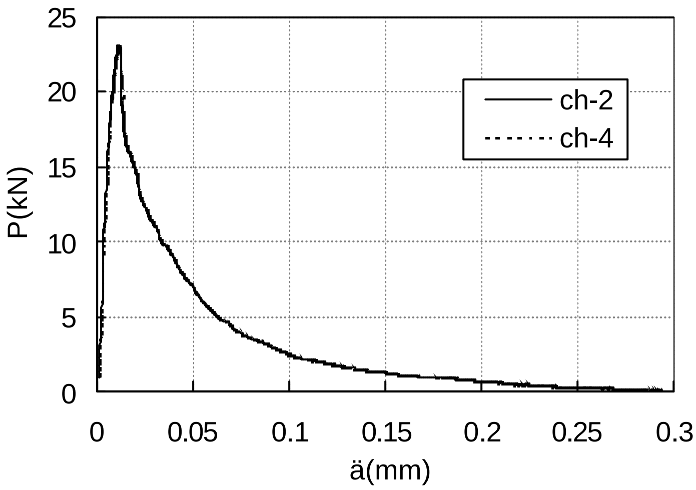

Fig. 3 load-deformation curves by eliminating secondary flexure

3 RESULTS AND DISCUSSIONS

Fig. 3 shows an example of load-deformation (P-δ) curves concerning opposite face deformations of specimen, for example ch-2 and ch-4. Two curves almost coincide with each other, meaning that there is no difference between the both opposite side deformations, in other words, secondary flexure is eliminated effectively. Although the figure is not presented here, the same result is also obtained for ch-1 and ch-3 which are the other couple of opposite deformations.

Fig. 4 shows an example of P-δ curves concerning ch-2 and ch-4 when secondary flexure is left to develop freely. The deformation of ch-2 increases monotonically whereas that of ch-4 first increases, then decreases and finally becomes compressed.

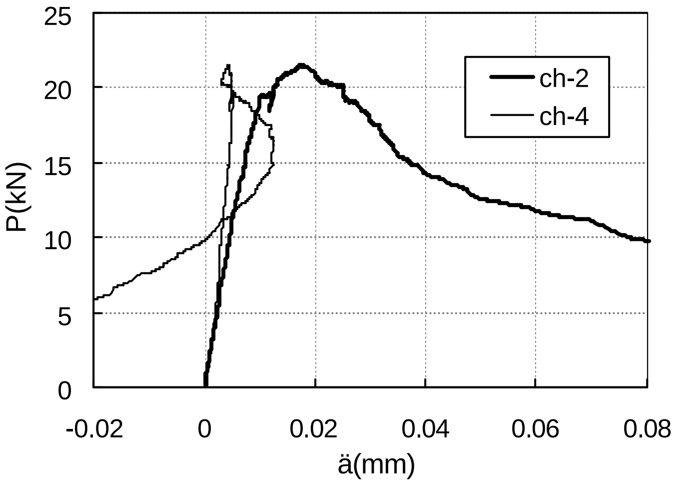

Fig. 4 load-deformation curves by leaving secondary flexure

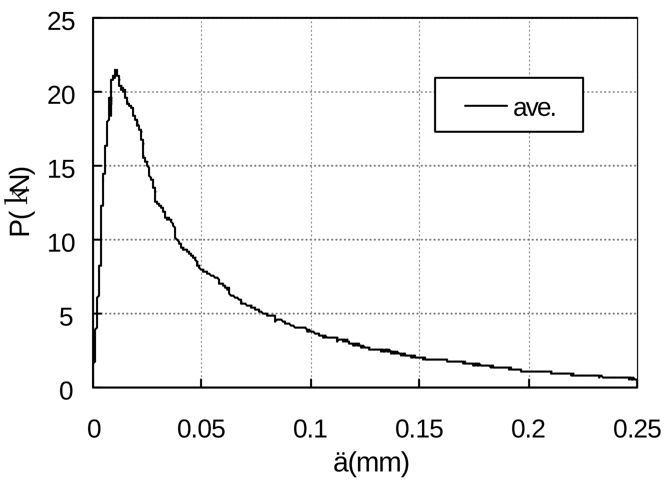

Fig. 5 load-deformation curve in average

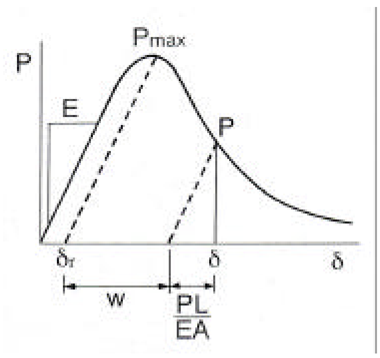

Fig. 6 relationship for calculation of COD

In spite of the irregular variation of each deformation, the P-δ curve obtained from the average of four side deformations of the identical specimen is specious as shown in Fig. 5. However, the average of elongation and compression will include large errors in the COD calculated in the ligament area.

The COD is calculated by subtracting elastic deformation from the average deformation within the measuring length as follows.

$$w = d - \frac{PL}{EA} - d_r \tag{1}$$

where δ: observed deformation, P: applied load, L: measuring length, E: Young's modulus, A: average of whole cross sectional area and ligament area, and δ_r : residual deformation when the load decreases to zero. The meaning of this formula is shown in Fig. 6. The deformation in the ligament area should be almost uniform for this direct calculation of COD. If the deformation varies significantly in the ligament area, the relationship between cohesive stress and COD cannot be calculated directly but by an inverse analysis.

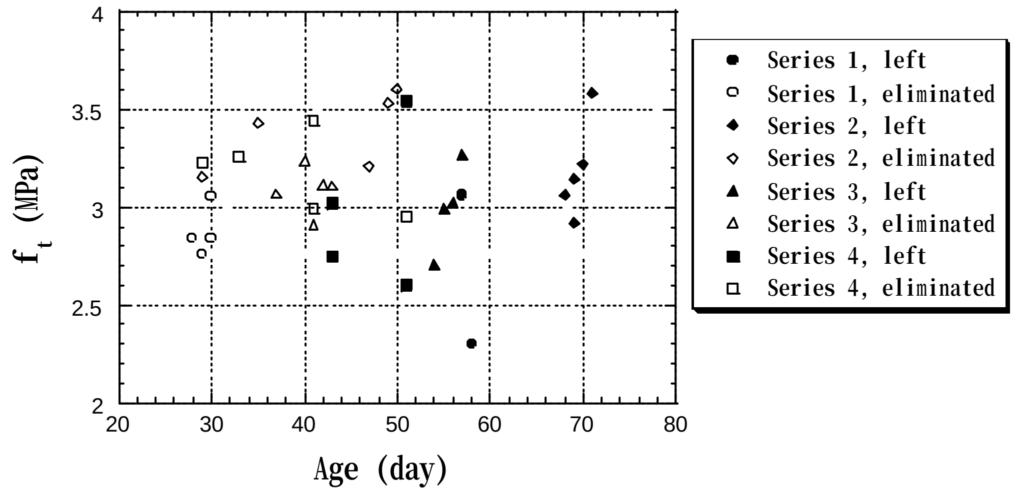

Fig. 7 Comparison of tensile strengths by the both treatments of secondary flexure

Fig. 7 shows tensile strengths obtained from both treatments of secondary flexure. Each tensile strength is expressed by age, because each test could not be performed with concrete of the same age. Series 1 to 4 are four concretes cast on different date by the same mix proportion. Tensile strengths when secondary flexure is left are smaller than when the flexure is eliminated. This result was also predicted by the simulation study [2]. It was reported that bending compressive stress superposed to tensile stress was the main cause of the reduction in measured tensile strength. In addition, significantly large scattering is recognized in the tensile strength when secondary flexure is left freely.

Fig. 8 shows fracture energies of each identical specimen obtained from the tension softening curve calculated by the area under the curve. Clear differences in fracture energies between the

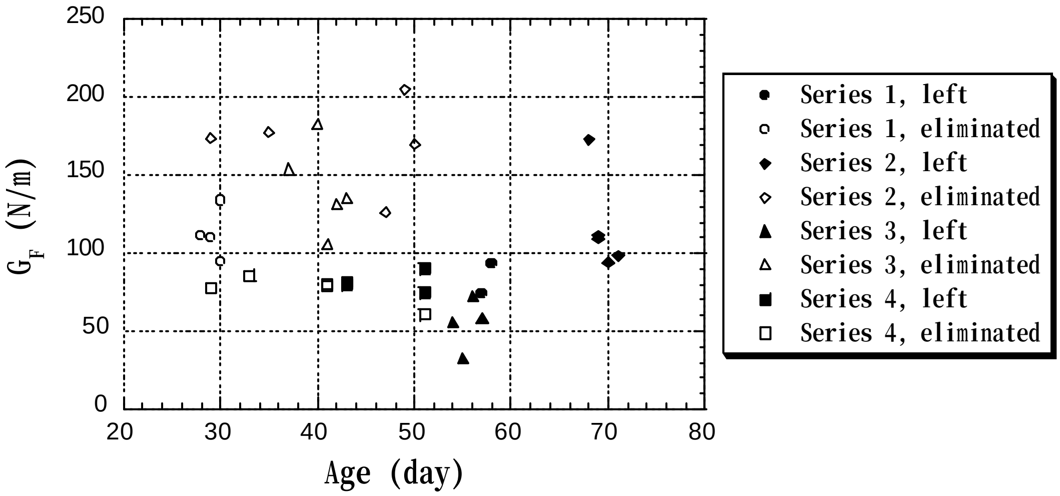

Fig. 8 Comparison of fracture energies by the both treatments of secondary flexure

two treatments, eliminating secondary flexure completely and leaving it freely, are observed in the figure. The latter is almost a half of the former in average considering their ages. In the simulation study [2], it was reported that the maximum load was always smaller when secondary flexure was left than when it was eliminated. It means that the maximum strain energy of the specimen is always smaller and results in measuring smaller fracture energy. In addition, the calculation by eq.(1) when deformation is an average of elongation and compression will include large errors.

4 CONCLUSIONS

From the experimental results of P-δ curves and magnitude of tensile strength and fracture energy, the difference between eliminating secondary flexure completely and leaving it freely was validated. The superiority of the former procedure is confirmed from several viewpoints.

REFERENCES

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2) Akita, H., Sohn, D. and Ojima, M., “Simulation study of secondary flexure versus fracture behavior of concrete under uniaxial tension loading”, Proceedings 6th International Symposium Brittle Matrix Composites, WOODHEAD Publishing LTD, Warsaw, Poland, pp. 371-378, 2000.