Benefits of Weight Difference of PP and Steel Fibers on Properties of Functionally Graded Fiber Reinforced Cementitious Composites (FG-FRCC)

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1. INTRODUCTION

The purpose of this study is to enhance the fiber effectiveness in functionally graded FRCC (FG-FRCC) by using the weight difference of polypropylene (PP) and steel fibers and improve the bending strength and toughness of FRCC. To achieve this, the distribution of fiber is controlled by changing the amount of thickener added to the matrix and the flow time by the funnel test is set as a parameter.

2. EXPERIMENT OUTLINE

Fig. 1 shows PP and steel fiber used in this study. Table 1 lists the dimensions and mechanical properties of these fibers. In order to enhance the fiber distribution by difference in weight of fibers, the amount of thickener was set to 4 levels of 0g, 20g, 40g, and 60g (TH0, TH20, TH40, TH60) with respect to the mixing amount of 30L. Table 2 shows the mixture proportion. The specimen was a prism with a cross section of 100mm*100mm and a length of 400mm. Table 3 shows the fresh properties and compression test results using a ϕ100-200mm cylinder test pieces. As the results of the funnel test, the flow time of matrix before mixing fibers varies from 24.3s to 136.2s. Five specimens were prepared for each and a four-point bending test with a pure bending span of 100 mm using a 2MN universal tester was carried out.

3. EXPERIMENTAL RESULT

3.1 Specimen status after loading

The typical examples of the cross section of specimens after loading are shown in Fig. 2. While PP fibers are concentrated in the upper part of TH0 specimen, the distributions are almost even as the addition of thickener. In all specimens, steel fibers are unevenly distributed at the bottom. In TH0, TH40 and TH60 specimens, the amount of steel fibers tends to decrease towards the upper part. In TH20 specimen, there are steel fibers in the upper part even though small in amount.

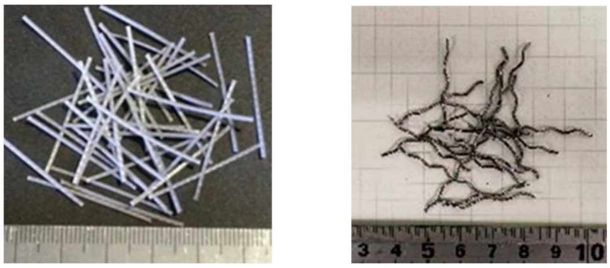

Fig. 1 Used fibers

Table 1 Dimensions and mechanical properties of fibers

Fiber type	Diameter [μm]	Length [mm]	Tensile strength [MPa]	Elastic modulus [GPa]	Density [g/cm^3]
Steel	800	30	1000	210	7.85
PP	700	30	580	4.9	0.91

Table 2 Mixture proportion

Unit weight [kg/m^3]					Fiber [kg] (1%)	Thickener [kg]
Water	Cement	Sand	Fly ash	Super-plasticizer		
380	678	484	291	6	PP:9.1 Steel:78.5	0 0.67 1.33 2

Table 3 Fresh properties and compression test results

Specimen	Flow time [s]	Temperature [℃]	Compressive strength [MPa]	Elastic modulus [GPa]
TH0	24.3	16.5	45.8	17.3
TH20	31.9	17.3	42.6	16.7
TH40	69.2	18.5	38.8	17.0
TH60	136.2	18.8	39.9	16.8

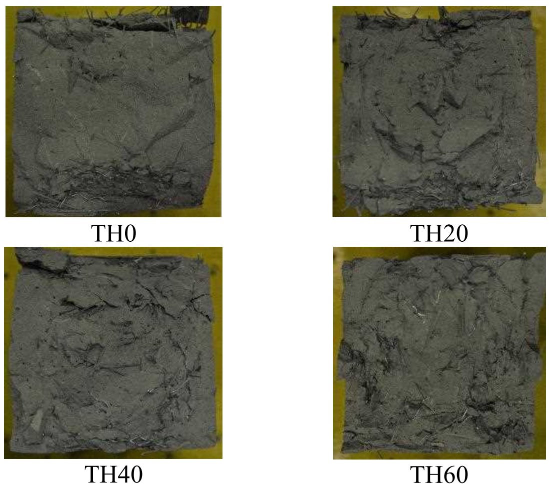

Fig. 2 Cross section of specimen after loading

Keywords FG-FRCC, Fiber distribution, Weight difference, Flow time, Thickener, Bending test
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3.2 Load-deflection relationship

Table 4 shows the average maximum load of each specimen. The load-deflection (average of load point deflections) relationships of each specimen are shown in Fig. 3. In the TH0 specimens, since the steel fibers were concentrated on the lower part, the load dropped significantly when cracks developed. In some specimens, fluctuation of the load in small steps was observed after the peak, which may be due to the wavy shape of steel fiber. TH20 specimens show the highest toughness because of the concentration of steel fibers at the bottom.

4. SECTION ANALYSIS

4.1 Method of analysis

Cross-section analysis is carried to investigate the effect of fiber distribution on the maximum bending moment. The number of fibers was counted visually after loading dividing the cross section into three parts in the height direction with the casting surface as the upper part as shown in Fig.4. The amount of steel fibers in TH60 specimen is used as a reference, the apparent fiber distribution ratio is obtained for each cross-sectional position (Table.5). Since the bridging effect of PP fiber is smaller than that of steel fiber, PP fiber is ignored. For the FRCC bridging law using steel fibers, a bilinear model is used with reference to the previous study [1].

4.2 Analysis result

Table 6 shows the comparison between the maximum bending moment obtained by analysis and experimental results. The bending moment by analysis exceeded the experimental result. In this analysis, the fiber distribution was expressed by dividing the cross section into three parts in the height direction. It is considered necessary to incorporate the actual fiber distribution into the analysis more accurately.

5. CONCLUTION

The results of the study showed that the test specimen TH20 showed the highest toughness because the fibers were distributed evenly throughout the matrix bridging the cracks efficiently. In the test specimen TH40 and TH60 fibers tend to concentrate unevenly on the bottom part. Therefore, by adding appropriate amount of thickener to the matrix, the weight difference of fibers can enhance the fiber effectiveness and properties of FG-FRCC.

Table 4 Average Maximum load

Specimen	Maximum load [kN]
TH0	13.9
TH20	16.7
TH40	17.7
TH60	17.1

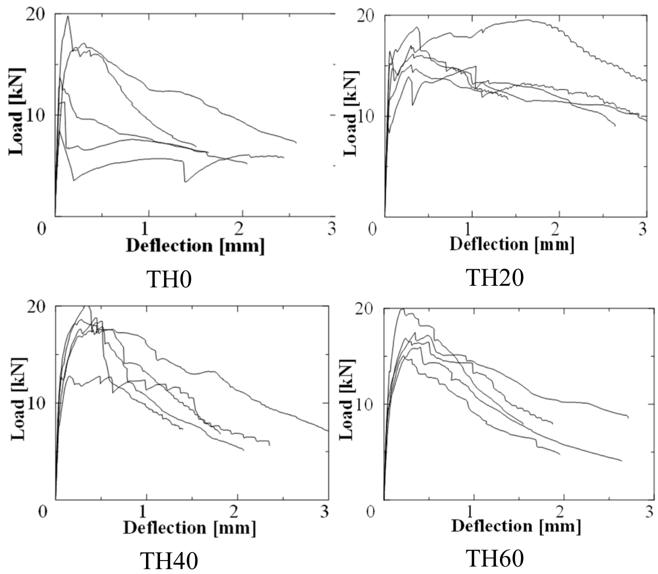

Fig. 3 Load-deflection relationship

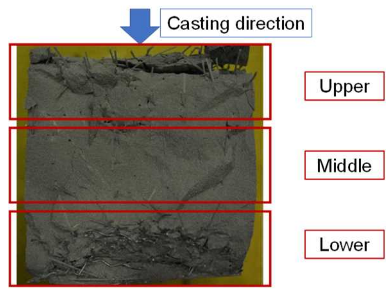

Fig. 4 Sections counting the number of fiber

Table 5 Apparent steel fiber ratio

Position	TH0	TH20	TH40	TH60
Upper	0.022	2.261	1.109	1.000
Middle	0.075	0.188	0.902	1.000
Lower	1.048	0.884	0.809	1.000

Table 6 Comparison of maximum bending moment

Specimen	Maximum bending moment [kN・m]		Experimental result / Analysis result
	Experiment	Analysis	
TH0	0.697	0.854	0.82
TH20	0.836	0.954	0.88
TH40	0.883	1.084	0.81
TH60	0.853	1.252	0.68

REFERENCE

[1] 須永大揮，古場匠，金久保利之：繊維種類による架橋則の違いが DFRCC 部材のひび割れ幅に与える影響，コンクリート工学年次論文集，Vol.43，No.2，pp.775～780，2021.7