- Technical Paper -

EXPERIMENTAL STUDY ON DRYING SHRINKAGE CRACKING CHARACTERISTICS OF STEEL CHIP REINFORCED POLYMER CEMENTITIOUS COMPOSITE

Sunhee HONG[*1], Shinya KIMURA[*2], Yuichi SATO[*3], Yoshio KANEKO[*4]

ABSTRACT

This study is to clarify the drying shrinkage and shrinkage cracking characteristics of steel chip reinforced polymer cementitious composite (SCRPCC). In this study, free shrinkage of SCRPCC, drying shrinkage and shrinkage cracking of SCRPCC reinforced with deformed bars were examined. Test results shows that (1) the free shrinkage of SCRPCC is smaller than that of polymer cement mortar (PCM) at the outside; (2) the restrained shrinkage of PCM specimens was reduced by reinforcing with steel chip; (3) average crack width of PCM specimen with low reinforcement ratio was greatly declined by reinforcing with steel chip.

Keywords: fiber reinforced cementitious composite, steel chip, reuse, polymer, drying shrinkage

1. INTRODUCTION

Since the adoption of Kyoto Protocol in 1997, reducing of CO_2 emission became important tasks in the entire industry. Among others, iron and steel industry represents one of the major constituents of industrial waste. Therefore, through the reuse of these steel materials, it can be contributed to reduce the environmental load. As a research about steel chip reinforced cementitious composite (SCRCC), there is a study on the shape memory alloy machining chips reinforced smart composite [1]. But the application to building structures is not economically practical. So, steel chip which is an industrial waste produced in iron works is economically efficient and environmentally sound because of industrial waste reduction. There have been a few researches on the drying shrinkage properties of fiber reinforced cementitious composites (FRCC) [2-4]. In addition, there is no experimental data about the shrinkage cracking characteristics of FRCC. Drying shrinkage, when restrained, contributes to nearly all the cracking observed in concrete members before loading. A free shrinkage test cannot give the true potential of fiber reinforcement to resist restrained shrinkage stresses and to control shrinkage cracking [5]. Therefore, it is necessary to examine not only free shrinkage, but also restrained drying shrinkage. So far, the authors have conducted a pilot experimental investigation of the free and restrained drying shrinkage of SCRCC made of ordinary Portland cement binder [6]. To enhance strength, adhesion, waterproofness and durability of building structures, the usage of polymer cement mortar is one of the promising solutions [7]. Hence, this research investigates the drying shrinkage properties and the cracking characteristics of the newly developed SCRPCC with large scale wall specimens [8, 9].

2. EXPERIMENTAL PROGRAMS

2.1 Materials

(1) Steel chip

Steel chip produced when steel plate is precisely machined on the NC (Numerical Controlled) lathe which is a machine tool for metal working was used in this study (Fig.1). Steel grade is SS400, and the density of steel chip is 7.86g/cm^3. Now, all these steel chips occurred during machining are being buried as wastes.

Fig.1 Steel chip

(2) Mix proportion

The mix proportions of cementitious composites used in this study are given in Table 1. Polymer cement mortar was used as a binder. Ordinary Portland cement was used as a cement. Polymeric admixture used is ethylene vinyl acetate (EVA) emulsion which is a fluid milk-white solution with a solid content of 45% and the density 1.07g/cm^3. And antifoaming is used to control the entrained air with 1% by mass on polymer. River sand was used as a fine aggregate. Steel chip contents of 3% by volume were used in this study.

(3) Material properties

Physical properties of cementitious composites used were shown in Fig.2 and listed in Table 2.

*1 Doctoral Candidate, Dept. of Architecture and Architectural Engineering, University of Kyoto, JCI Member
*2 Graduate Student, Dept. of Architecture and Architectural Engineering, University of Kyoto
*3 Assistant Prof., Dept. of Architecture and Architectural Engineering, University of Kyoto, Dr. E., JCI Member
*4 Prof., Dept. of Architecture and Architectural Engineering, University of Kyoto, Ph.D., JCI Member

2.2 Test Specimens

Specimens for free shrinkage test are beam specimens of size 100×100×500mm. On the other hand, four large specimens of 2,500 mm length for restrained drying shrinkage test are prepared as shown in Fig.3. The parameters of specimens are listed in Table 3.

Table 1 Mix proportion of cementitious composites

	PCM	SCRPCC
Water-cement ratio, W/C (%)	30	
Cement :Sand (by mass)	1:2	
Polymer-cement ratio, P/C (%)	10	
Steel chip (Vol. %)	0	3

Table 2 Properties of cementitious composites

	PCM	SCRPCC
Compressive strength f'_c (N/mm^2)	39.1	38.2
Strain corresponding to compressive strength ε_c (×10^{-3})	4.1	7.3
Tensile strength f_t (N/mm^2)	3.9	4.4

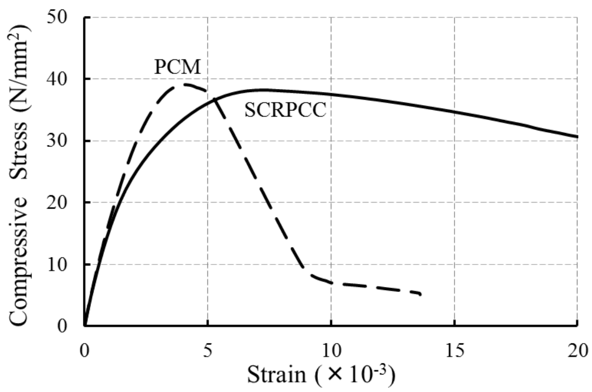

Fig.2 Relationship between compressive stress and strain of cementitious composites

2.3 Test Procedure

Firstly, the casting form was arranged and restraining steel bars were placed. The steel bars were consisted of four or ten deformed bars of 6mm diameter with 180°hooks in the both ends. Secondly, the restraining block (450×600×300mm) was casted with normal concrete (NC, f'_c=58.6N/mm^2). Each block was fixed with four prestressing bars of 32 mm diameter, to which 250 kN tensile force was applied. Thirdly, the center part (2500×300×150mm) was casted with PCM or SCRPCC. Fig.4 shows the casting process of the

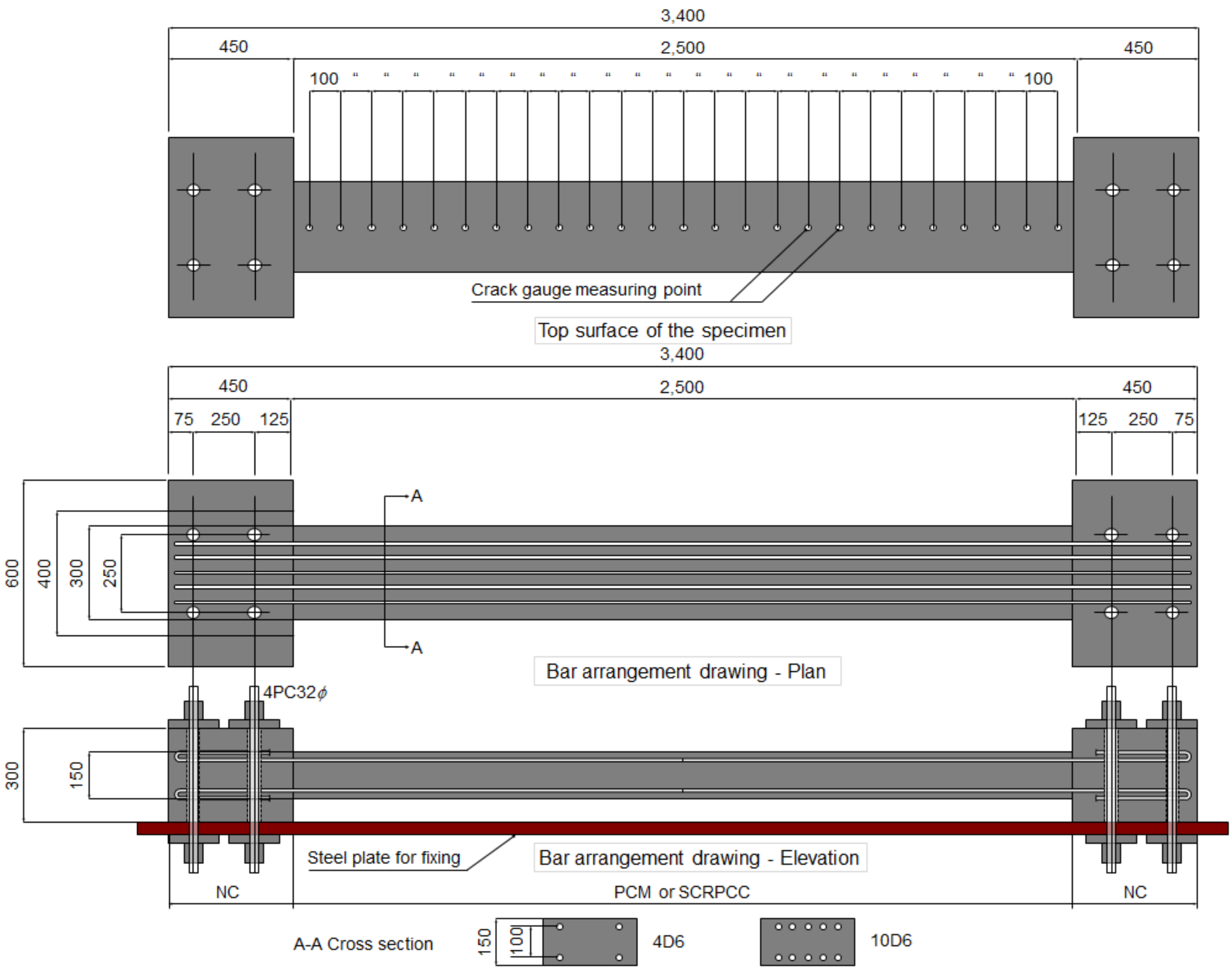

Fig.3 Specimens of restrained drying shrinkage test

Mixing of mortar　　Casting　　Completion

Fig.4 Casting process of the center part

center part. After the casting form was removed (curing 5days), Beam specimens (100×100× 500mm) for free shrinkage and wall specimens (300×150×2500mm) for restrained drying shrinkage were cured for 5days at the each curing conditions. Then 25 measuring targets were bonded on the surface of specimen with every 100mm. And initial measurement was started (curing 7 days). Then this point was fixed as a standard point (drying period 0day). The measuring of strains and the observation of crack patterns were conducted every 7 days during first 56days, and every 14days after the 56days.

Table 3 Specimens

Specimen	Curing condition	Restrain	Mortar	Bar
PCM-In	20℃, 60% R.H	Free	PCM	-
SCP-In	20℃, 60% R.H	Free	SCRPCC	-
PCM-Out	Outdoor	Free	PCM	-
SCP-Out	Outdoor	Free	SCRPCC	-
PCM4	Outdoor	Restrained	PCM	4D6
SCP4	Outdoor	Restrained	SCRPCC	4D6
PCM10	Outdoor	Restrained	PCM	10D6
SCP10	Outdoor	Restrained	SCRPCC	10D6

3. TEST RESULTS AND DISCUSSION

3.1 Curing and drying condition

Two beam specimens for the free shrinkage test (PCM-In and SCP-In) were subjected to a constant temperature and humidity condition of 20℃ and 60R.H. On the other hand, two beam specimens (PCM-Out and SCP-Out) and four wall specimens (PCM4, SCP4, PCM10 and SCP10) were subjected to the outdoor condition and kept from the rain. Average daily temperature and average daily humidity of the outdoor that specimens were exposed to during drying period are shown in Fig.5 and Fig.6.

3.2 Shrinkage strains and crack patterns

(1) Free shrinkage

Fig.7 represents the relationship between drying shrinkage of free shrinkage specimens and drying period. Overall, drying shrinkage of all specimens was increased with drying period. And the drying shrinkage was decreased by reinforcing with steel chip at the outside condition. However, the shrinkage of SCRPCC was slightly larger than that of PCM at the indoor condition. Effect of curing condition on drying shrinkage is that drying shrinkage of specimens in the outdoor condition was decreased as compared with that of indoor specimens. This is explained by the reason that the temperature and humidity of outdoor were irregular, and the temperature was always below 20℃, however, indoor was always maintained constant condition of 20℃, 60% R.H.

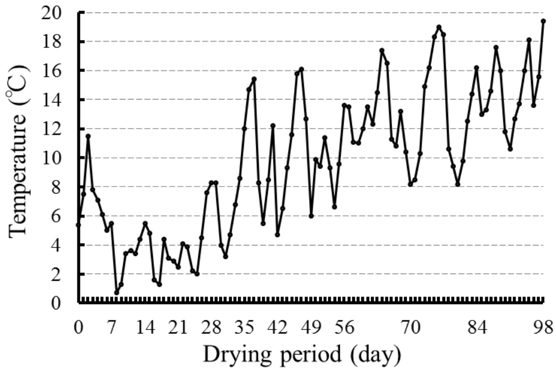

Fig.5 Average daily temperature

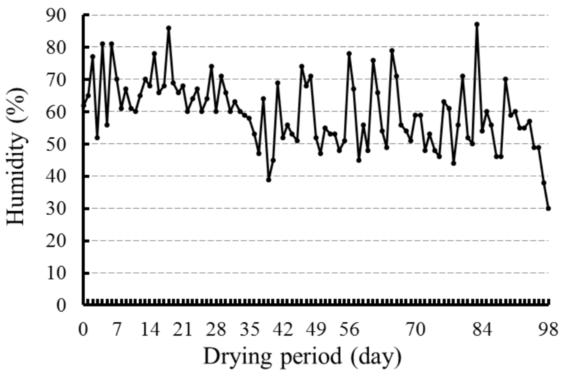

Fig.6 Average daily humidity

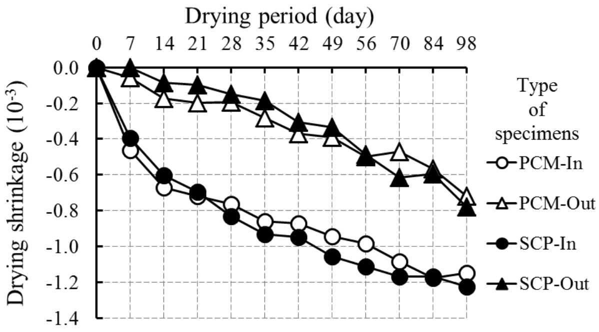

Fig.7 Relationship between drying shrinkage of free shrinkage specimens and drying period

(2) Restrained shrinkage and cracking characteristic

Figs.8 to 11 shows the drying shrinkage and crack patterns for three sides of each specimen.

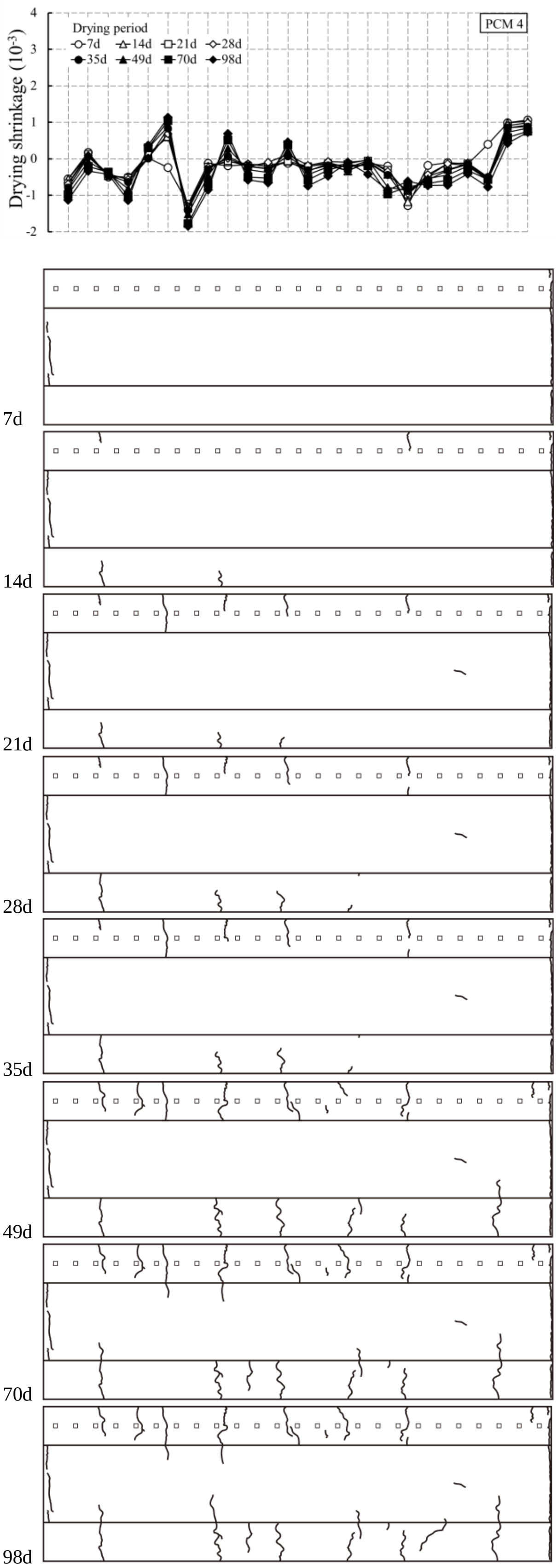

Fig.8 Drying shrinkage and crack patterns of specimen PCM4

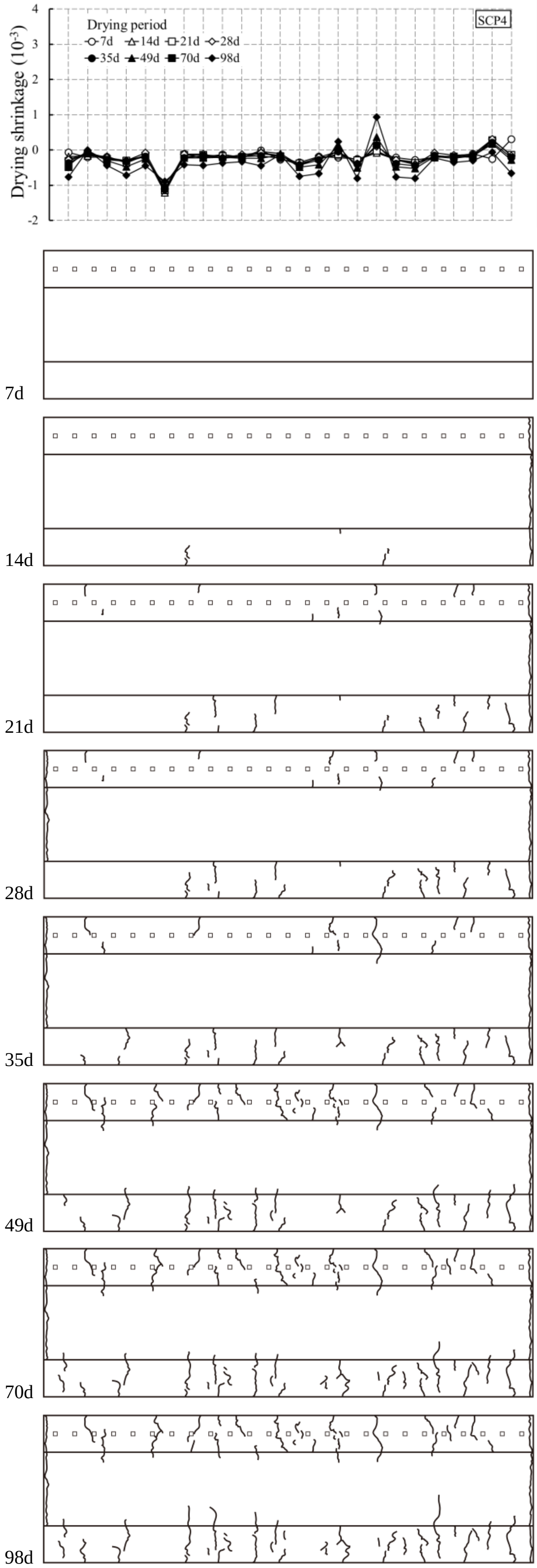

Fig.9 Drying shrinkage and crack patterns of specimen SCP4

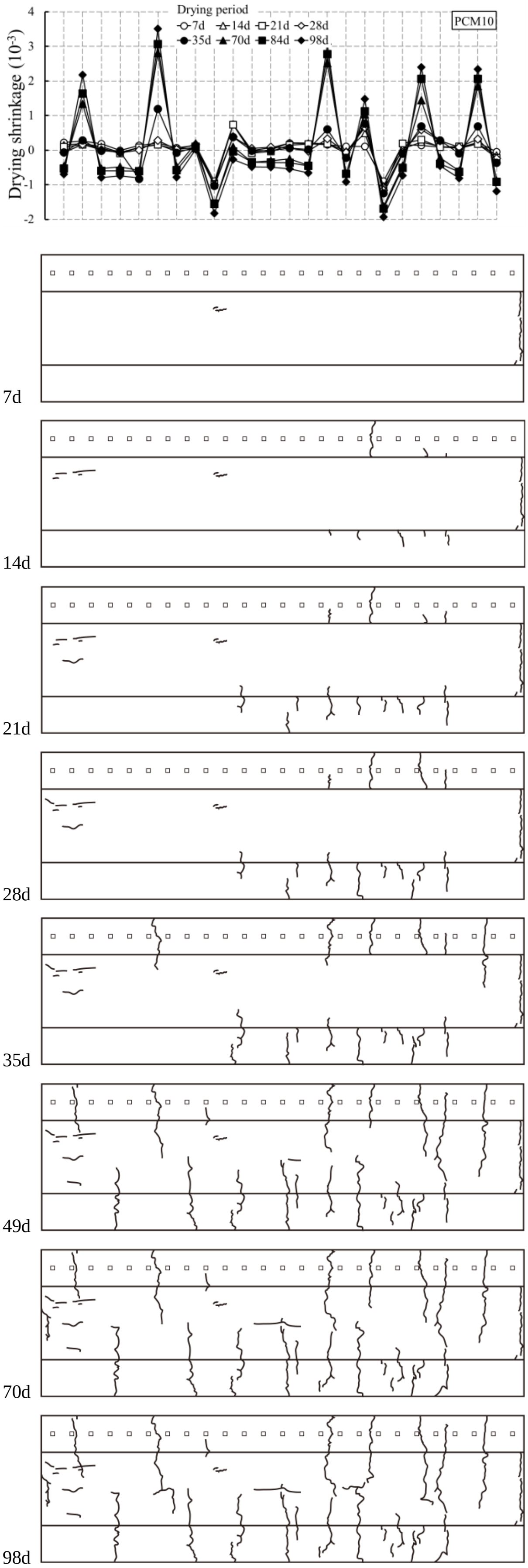

Fig.10 Drying shrinkage and crack patterns of specimen PCM10

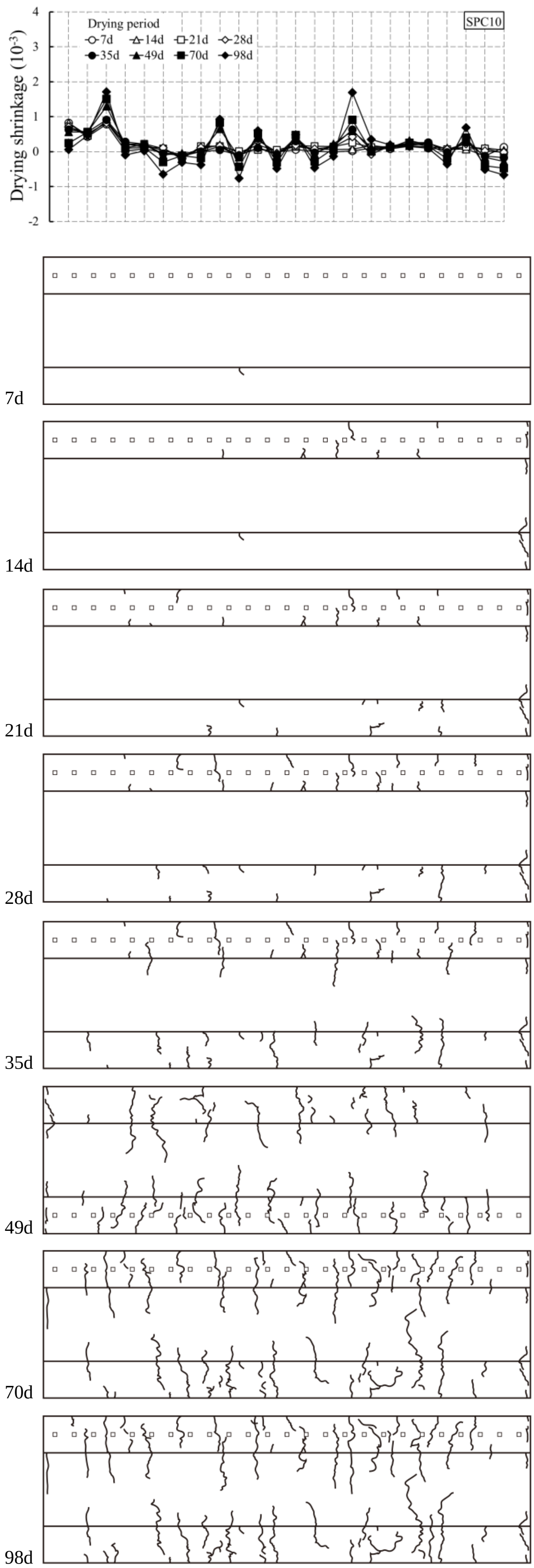

Fig.11 Drying shrinkage and crack patterns of specimen SCP10

Drying shrinkage of restrained PCM specimens was inclined to decrease with reinforcing with steel chip. The reason for this decrease is because the bridging effect was provided by reinforcing with steel chip, and the bond strength of binder was increased in the cement matrix.

Cracking characteristic is that in the case of specimens with high reinforcement ratio (PCM10, SCP10), the occurrence of cracks of the restrained specimen made of SCRPCC was less than that of PCM, and in the case of specimens with low reinforcement ratio (PCM4, SCP4), there is not so much difference on the number of cracks of both specimens.

Fig.12 shows relationship between average crack width and drying period. In order to calculate w_{cr}, first of all, equivalent number of cracks was calculated by Eq. 1. After that, average crack width was calculated by Eq. 2. The number of cracks N_{cre} is defined as total lengths of cracks on the top surface of the specimen divided by the width (300 mm). Equivalent number of cracks N_{cre} is used since only a few cracks penetrate the entire width of the specimen.

$$N_{cre} = \Sigma(l_{cr})/300 \quad (1)$$

$$w_{cr} = (L \times \mathcal{E}_{cd}) / N_{cre} \quad (2)$$

N_{cre} : Equivalent number of cracks
l_{cr} : length of a crack on the top surface of the specimen (mm)
w_{cr} : average crack width of restrained specimen (mm)
L : length of a restrained specimens (= 2500 mm)
$\mathcal{E}_{cd}$: free drying shrinkage of outdoor specimen

Overall, average crack width of restrained specimens was decreased by increasing of the amount of reinforcing bar. In the case of specimens with low reinforcement ratio (PCM4, SCP4), average crack width of PCM specimen was decreased by reinforcing with steel chip. And average crack width of specimens with high reinforcement ratio (PCM10, SCP10) was that PCM specimen was lower than SCP specimen.

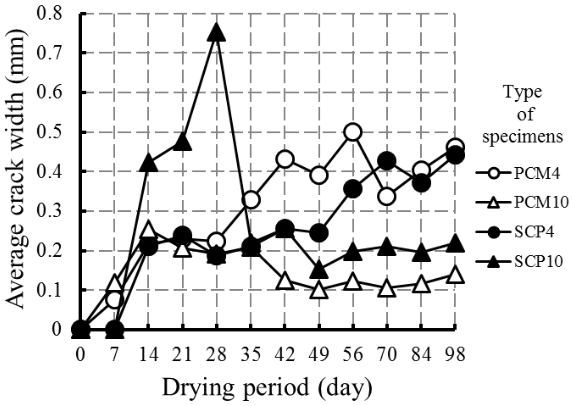

Fig.12 Relationship between average crack width and drying period

4. CONCLUSIONS

In this paper, the drying shrinkage properties and the cracking characteristics of the newly developed SCRPCC with large scale wall specimen were investigated. The following conclusions can be obtained.

(1) Drying shrinkage of all free shrinkage specimens was increased with drying period. And the drying shrinkage was decreased by reinforcing with steel chip at the outdoor condition. Influence of curing and drying condition on drying shrinkage is that drying shrinkage of outdoor specimens was lower than that of indoor specimens.

(2) Drying shrinkage of restrained PCM specimens was reduced by reinforcing with steel chip. And in the case of specimens with high reinforcement ratio, the occurrence of cracks of restrained SCRPCC specimen was less than that of PCM specimen.

(3) Average crack width of restrained specimens was decreased by increasing of the amount of reinforcing bar. And in the case of specimens with low reinforcement ratio, average crack width of PCM specimen was declined by reinforcing with steel chip.

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