- Technical Paper -

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

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ABSTRACT
This study is to clarify the drying shrinkage and shrinkage cracking characteristics of steel chip reinforced cementitious composite (SCRCC). In this study, free shrinkage of SCRCC, drying shrinkage and shrinkage cracking of SCRCC reinforced with deformed bars were examined. Test results shows that (1) the free shrinkage of SCRCC is smaller than that of the normal mortar; (2) number of cracks of the restrained specimen made of SCRCC is smaller than that of the normal mortar; and (3) number of cracks in the restrained specimen increases as the reinforcement content increases.
Keywords: fiber reinforced cementitious composite, steel chip, reuse, drying shrinkage

1. INTRODUCTION

Iron and steel industry represents one of the major constituents of industrial waste. 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. This research investigates the drying shrinkage properties and the cracking characteristics of the newly developed SCRCC with large scale wall specimens [5, 6]. 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 [7]. Therefore, in this study, not only free shrinkage but also restrained drying shrinkage is examined.

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). Now, all these steel chips occurred during machining are being buried as wastes.

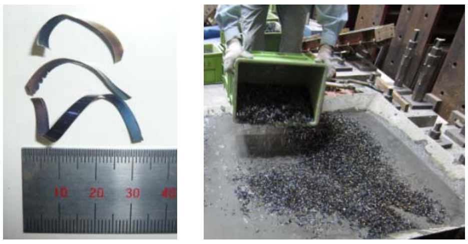

Fig.1 Steel chip

(3) Mix proportion

The mix proportions of cementitious composites used in this study are given in Table 1. Ordinary Portland cement and silica fume were used as a binder. River sand was used as a fine aggregate. And high performance air entraining and water reducing agent was used to reduce the unit water content of cementitious composites. Steel chip contents of 3% by volume were used in this study.

Table 1 Mix proportion of cementitious composites

	Normal Mortar (NM)	SCRCC (SC)
W/B (%)	23.3	23.3
Water (kg)	25.239	25.239
Cement (kg)	85.634	85.634
Fine aggregate (kg)	130.803	118.514
Silica fume (kg)	22.694	22.694
Steel chip (Vol. %)	0	3
Chemical admixture (kg)	2.355	2.355

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(4) Material properties

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

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.

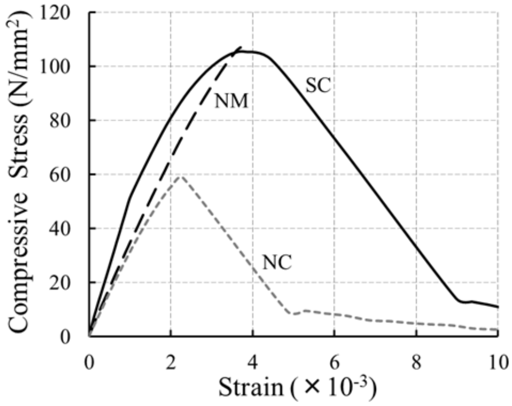

Fig.2 Relationship between compressive stress and strain of cementitious composites

Table 2 Properties of cementitious composites

	Normal Concrete (NC)	Normal Mortar (NM)	SCRCC (SC)
Compressive strength f'_c (N/mm^2)	58.6	107.0	105.4
Strain corresponding to compressive strength ε_c (×10^{-3})	2.30	3.70	3.80
Tensile strength f_t (N/mm^2)	-	4.3	9.0

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 6 mm diameter with 180°hooks in the both ends. Secondly, the restraining block (450 mm x 600 mm x 300 mm) was casted with normal concrete (NC). 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 mm x 300 mm x 15 0mm) was casted with normal mortar (NM) or SCRCC (SC). Fig.4 shows the casting process of the center part.

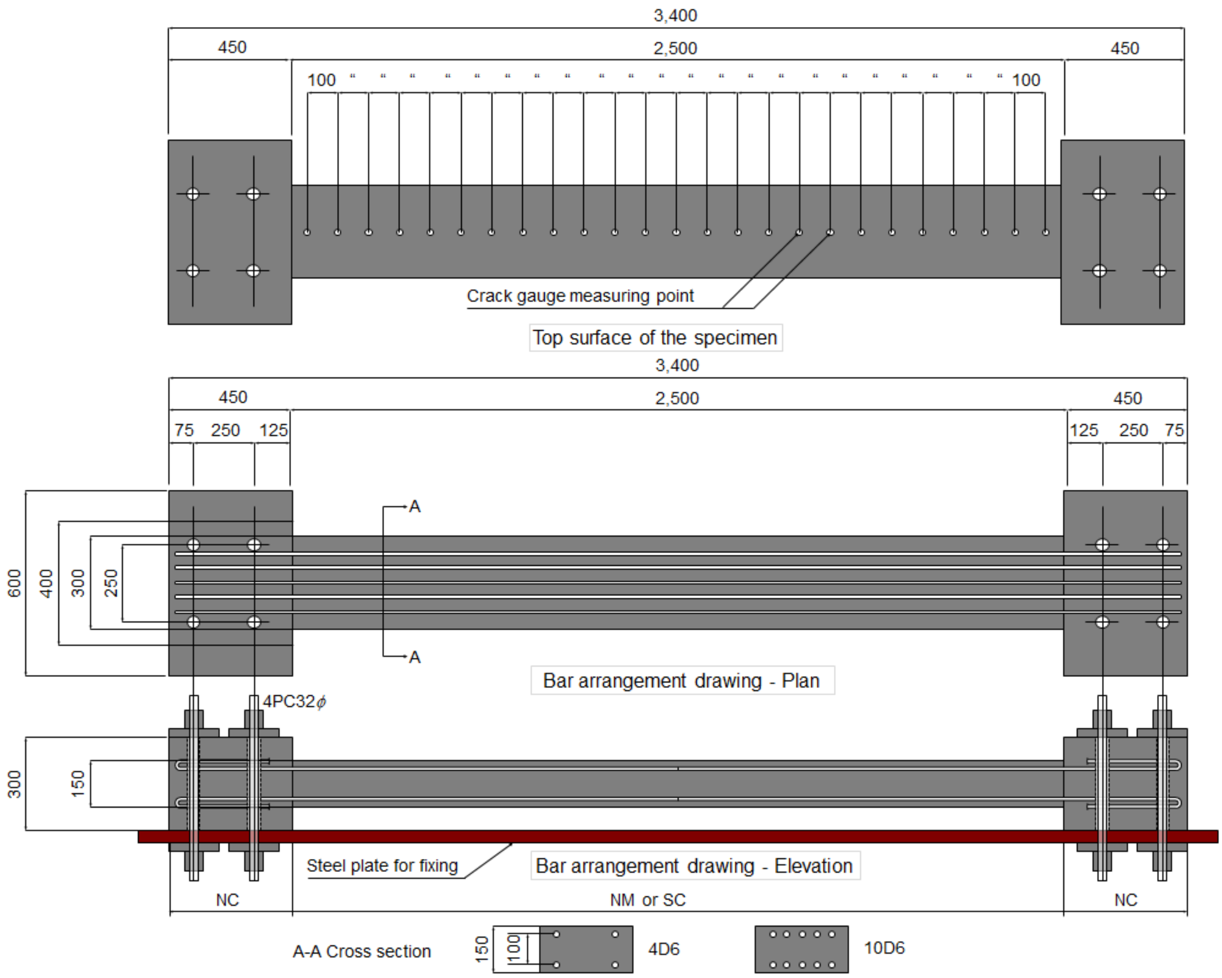

Fig.3 Specimens of restrained drying shrinkage test

Mixing of mortar　　Casting　　Completion

Fig.4 Casting process of the center part

Table 3 Specimens

Specimen	Curing condition	Restrain	Mortar	Bar
NM-In	20°C, 60% R.H	Free	Normal	-
SC-In	20°C, 60% R.H	Free	SCRCC	-
NM-Out	Outside	Free	Normal	-
SC-Out	Outside	Free	SCRCC	-
NM4	Outside	Restrained	Normal	4D6
SC4	Outside	Restrained	SCRCC	4D6
NM10	Outside	Restrained	Normal	10D6
SC10	Outside	Restrained	SCRCC	10D6

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 each 100 mm spacing. 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 at each seven days.

3. TEST RESULTS AND DISCUSSION

3.1 Curing and drying condition

Two beam specimens for the free shrinkage test (NM-In and SC-In) were subjected to a constant temperature and humidity condition of 20℃ and 60R.H.. On the other hand, two beam specimens (NM-Out and SC-Out) and four wall specimens (NM4, SC4, NM10 and SC10) were subjected to the outside condition and kept from the rain.

Average daily temperature and average daily humidity of the outside 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. Effect of curing condition on drying shrinkage is that drying shrinkage of specimens in the outside condition was lower than indoor specimens. This is explained by the reason that the humidity of outdoor was almost more than 60%, however, humidity of indoor was always 60%.

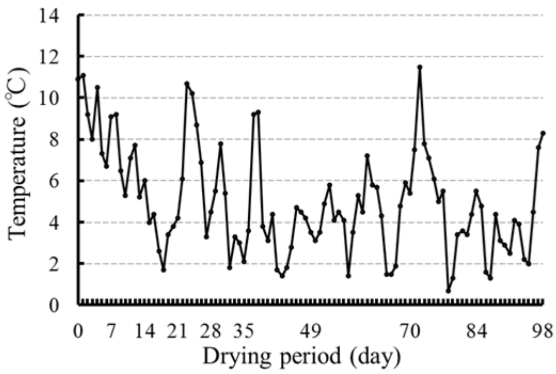

Fig.5 Average daily temperature

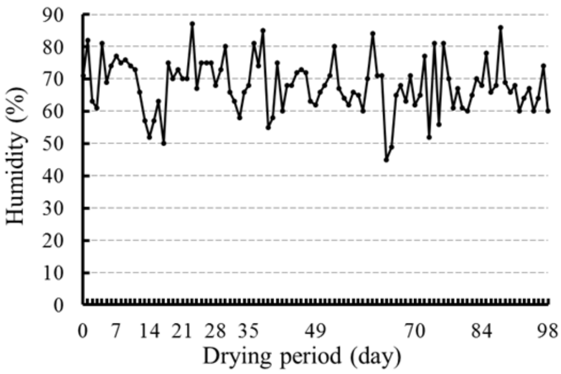

Fig.6 Average daily humidity

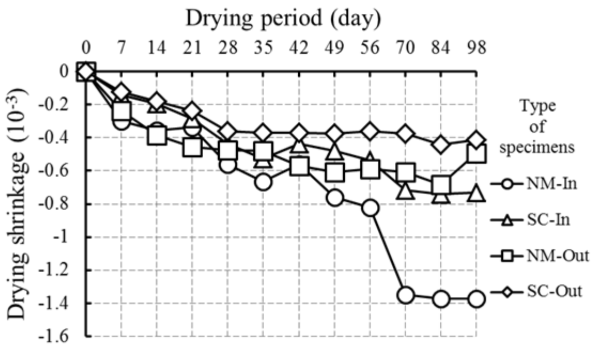

Fig.7 Relationship between drying shrinkage of free shrinkage specimens and drying period

(2) Restrained shrinkage and cracking characteristic

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

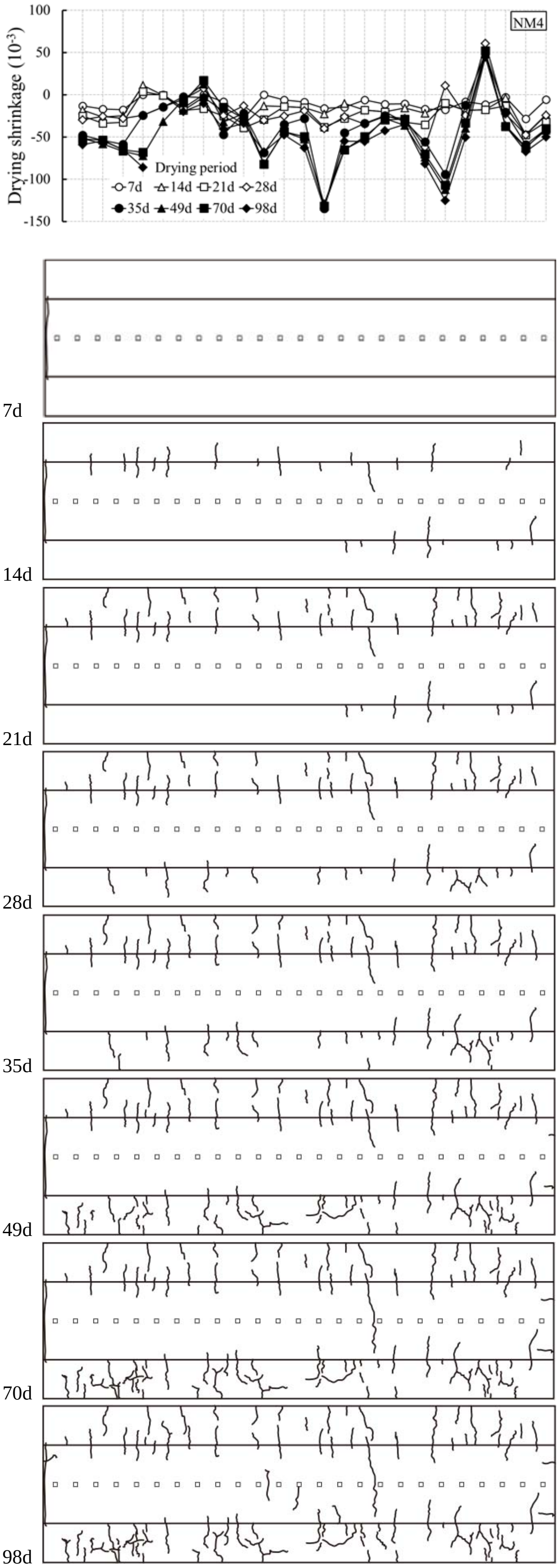

Fig.8 Drying shrinkage and crack patterns of specimen NM4

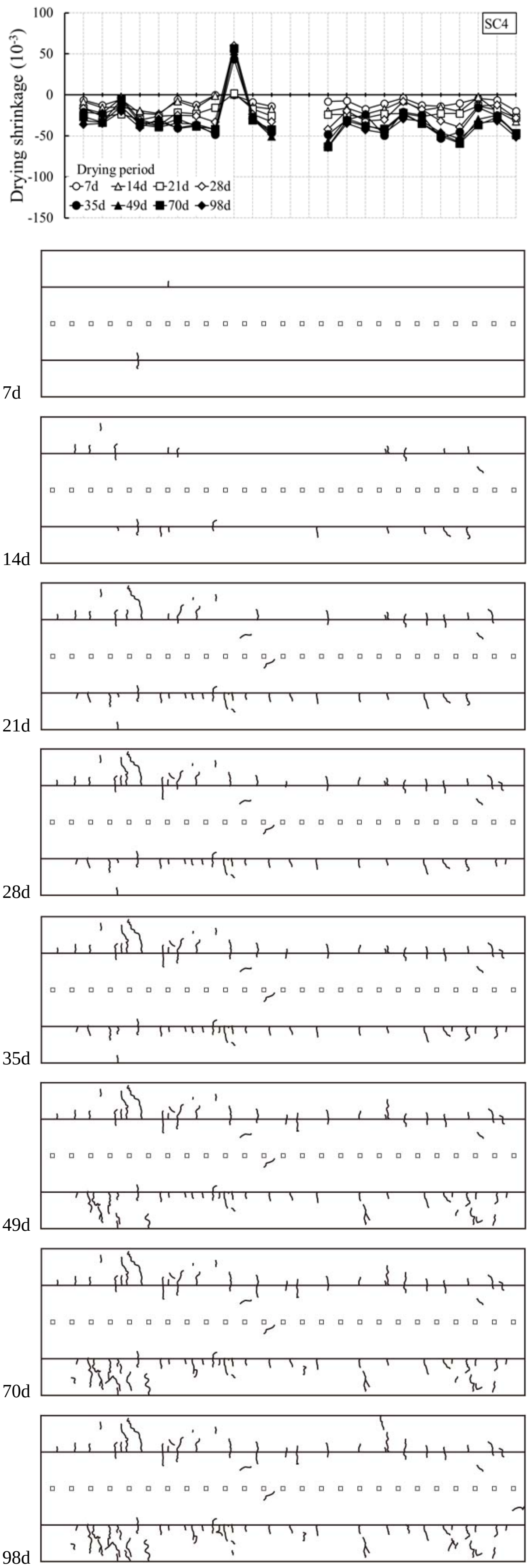

Fig.9 Drying shrinkage and crack patterns of specimen SC4

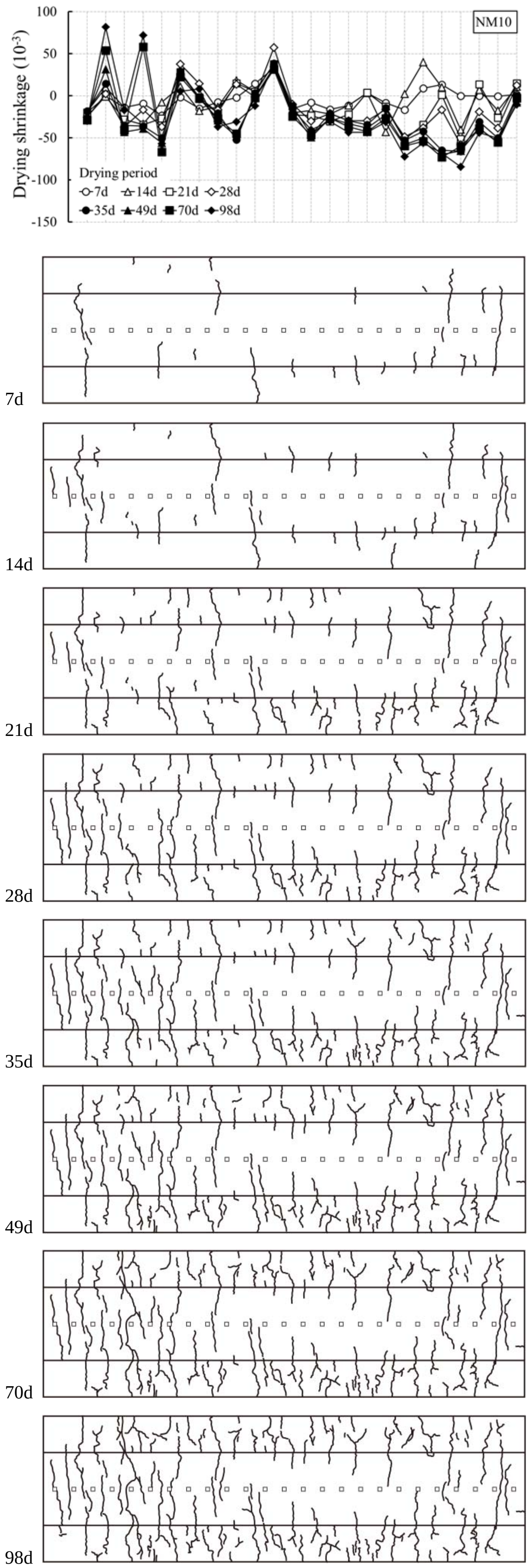

Fig.10 Drying shrinkage and crack patterns of specimen NM10

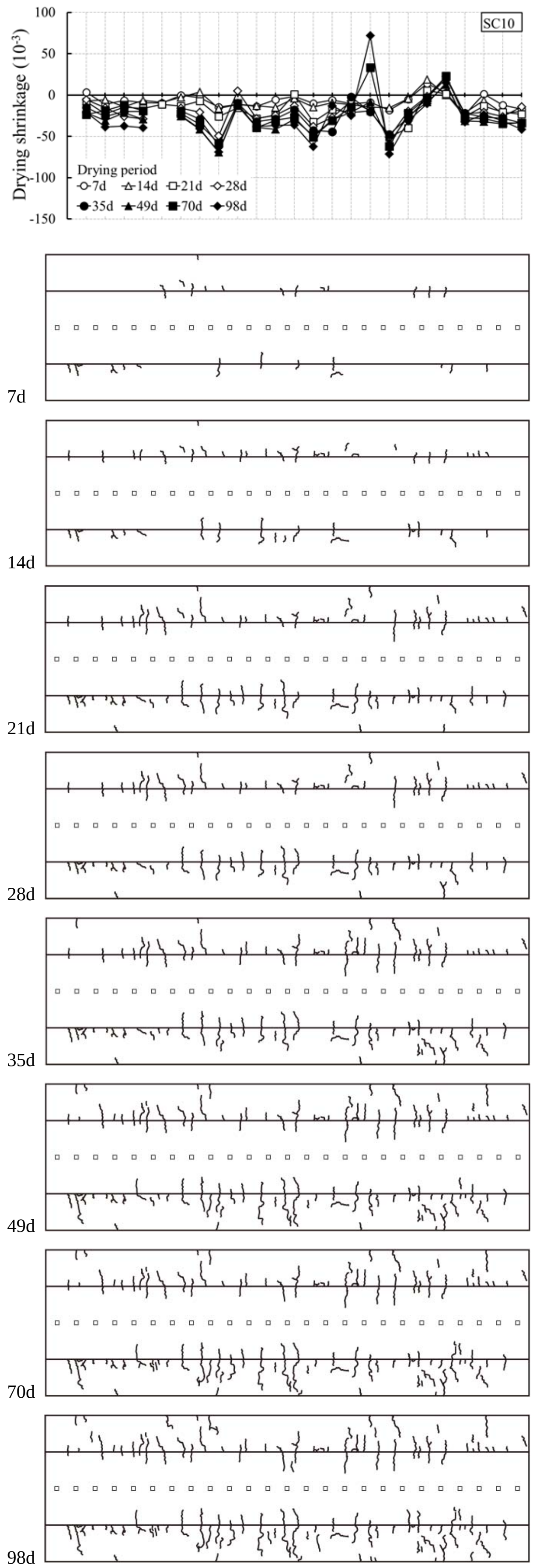

Fig.11 Drying shrinkage and crack patterns of specimen SC10

Drying shrinkage of cementitious composite was inclined to decrease with reinforcing with steel chip and increasing of amount of reinforcing bars. 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 occurrence of the cracks of SC specimens were less than that of NM specimens. And increasing of the amount of reinforcing bar increased the occurrence of cracks.

Fig.12 shows relationship between the equivalent number of cracks and drying period. The equivalent 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). l_{cr} is length of a crack on the top surface of the specimen. Equivalent number of cracks N_{cre} is used since only a few cracks penetrate the entire width of the specimen.

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

Generally, the number of cracks of all specimens was increased with drying period and increasing of the amount of reinforcing bars. However, the number of cracks of NM was decreased by using steel chip (SC).

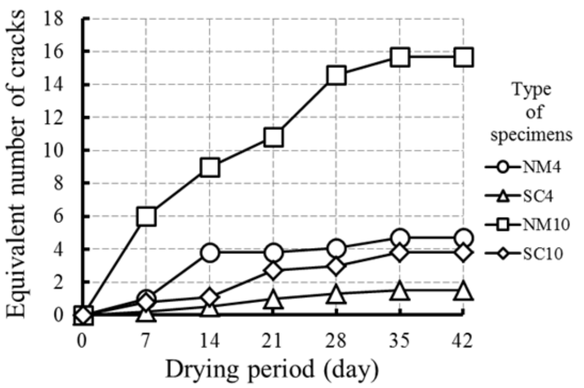

Fig.12 Relationship between equivalent number of cracks of specimens and drying period

4. CONCLUSIONS

In this paper, the drying shrinkage properties and the cracking characteristics of the newly developed SCRCC 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. Influence of curing and drying condition on drying shrinkage is that drying shrinkage of outdoor specimens was inclined to decrease as that of indoor specimens.

(2) Drying shrinkage of restrained specimens was reduced by reinforcing with steel chip, and decreased with increasing of the amount of reinforcing bars.

(3) Equivalent number of cracks of restrained specimens was increased with drying period, but decreased with reinforcing with steel chip and decreasing of the amount of reinforcing bar.

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