- Technical Paper -

THE EXPANSION CHARACTERISTICS OF SELF-COMPACTING CONCRETE WITH EXPANSIVE AGENT

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ABSTRACT

Expansive concrete was divided into paste and aggregate and the ideal of the friction and normal resistant force was proposed to explain the different resistant mechanism of fine and coarse aggregate. As same weight of expansive additive was employed for SCC with different amount of coarse aggregate, the expansion strain reduced with the reducing of coarse aggregate. Therefore the amount of expansive additive was suggested to increase on SCC in order to get same expansion comparing with the application of conventional concrete. This phenomenon was explained by the ratio of expansive additive to total powder, E/(C+E).
Keywords: Self-compacting concrete; expansive concrete; expansive additive

1. INTRODUCTION

The main performance of Self-compacting concrete (SCC), high fluidity and segregation resistance, is usually achieved by reducing the water/powder ratio [1]. Therefore, the volume shrinkage at the hardening and drying process are increased. The shrinkage together with the weak tensile strength may result in the occurrence of injurious cracking. To overcome this drawback, expansive additive is considered to add into SCC.

From the past researches, it has been reported that the expansion characteristics of expansive concrete differ greatly depending on concrete mix proportions and curing methods [2]. As mentioned above, in order to keep sufficient viscosity of SCC to avoid material segregation, a large amount of cement was employed in SCC. Therefore, most of the mix proportions of SCC were low water-to-cement ratio and high paste volume. Moreover, when concrete passed the complicated cross section or heavy reinforcement zone, good passing ability was indispensable to avoid block. Therefore the amount of coarse aggregate was limited to assure the passing ability. That was to say that the amount of powder was the key of the viscosity and the amount of coarse aggregate was related to passing ability. According to previous two characteristics of mixing proportions, the expansion characteristics of SCC were assumed to be different with the conventional concrete on the application of expansive additive.

In this research, the expansion characteristics of SCC using expansive additive was investigated by experimental method. Experiments of different rank of SCC (R1, R2 and R3) were executed with the same water-to-powder ratio and amount of expansive additive. Then, the expansion tendency was explained by the density of expansive additive in the paste and the expansive resistance of aggregate.

2. EXPERIMENTAL PROCEDURES

2.1 Materials and mix proportions

The materials in use and the mix proportions were shown in Table 1 and Table 2. The water-to-cement ratio and the ratio of sand to mortar in volume (Vs/Vm) were fixed at 30% and 45% and 40kg/m^3 of expansive additive was employed to replace cement for all mix proportions. The only one varied parameter was the absolute volume of coarse aggregate. The mix proportion of G0.29, G0.32 and G0.35 represented that the absolute volume of coarse aggregate was 0.29, 0.32 and 0.35m^3/m^3 respectively.

One-axial restraint specimen was prepared and deformed bar was installed in the center of the cross-section. Besides, the mold gauge was set in the middle of specimen and connected to data logger. The outline of specimen was shown in Fig.1.

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Table 1 Materials used for concrete

Cement	Low Heat Cement：Specific gravity 3.24
Expansive additive	CSA System：Specific gravity 3.20
Admixture	Polycarboxylic acid-based AE HWRA：Specific gravity 1.05
Fine Aggregate	Crushed sand：Specific gravity 2.60；Absorption 1.37% Sea sand ：Specific gravity 2.58；Absorption 1.94%
Coarse Aggregate	Crushed stone：Specific gravity 2.68
Steel	Young's Modulus=210 kN/mm^2

Table 2 Mix Proportions of concrete

No.	W/(C+E)	V_s/V_m	E/(C+E)	W	C	E	C.S	S.S	G_{1505}	G_{2015}	SP
				Unit：kg/m^3							
G0.29EX40	30%	45%	6.51%	184	574	40	397	394	546	234	7.98
G0.32EX40	30%	45%	6.80%	176	548	40	380	377	601	257	7.64
G0.35EX40	30%	45%	7.12%	168	522	40	363	360	655	281	7.30

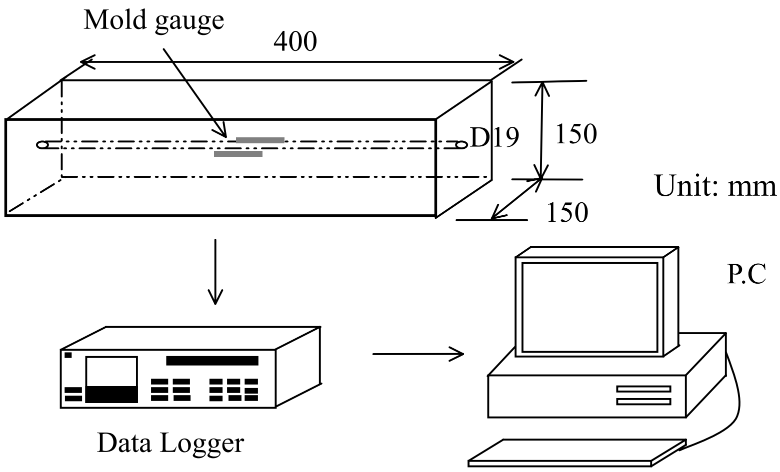


Fig.1 Outline of specimen

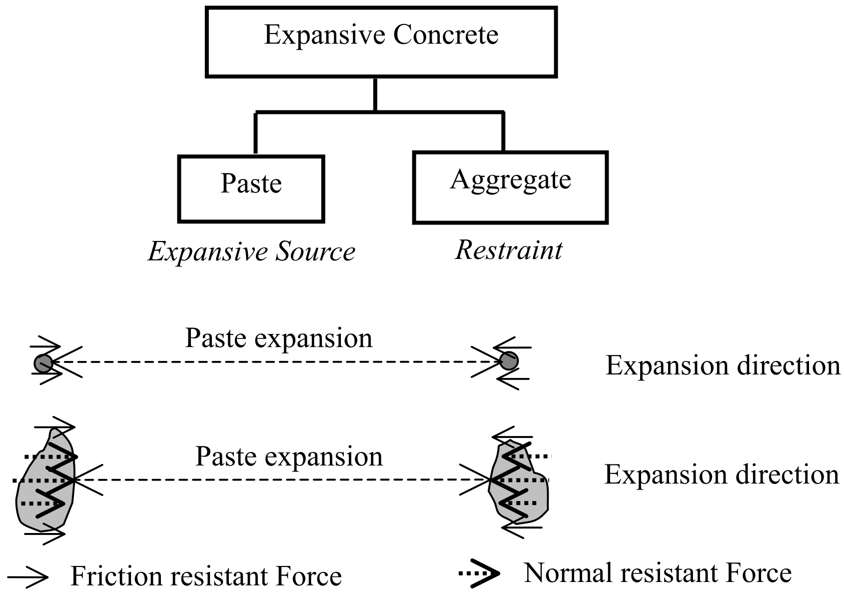
2.2 Measurement and curing methods

The formwork was removed at the age of 1 day. After the mold was removed, all specimens were cured in the water until the age of 7 day. During this time, the expansion strain of concrete was measured from data logger connected to the mold gauge in the center of specimen.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Mission of aggregate on the resistance of expansive concrete

The brief image of expansion concrete was introduced firstly. Expansion concrete was divided as two parts (paste and aggregate). Due to the addition of expansive additive into the paste, the deformability of paste was changed from shrinkage to expansion with the cement hydration reaction. Therefore paste was regarded as the expansive source. Besides, aggregate was regarded as the restraint role. However, the restraint mechanism of aggregate was different depending on the size. In the case of fine aggregate, the main restraint force comes from the friction between fine aggregate and paste. As to the coarse aggregate, except the friction mentioned above, the main resistant force was the normal force. Here, normal resistant force means the force occurred on the interface of paste and aggregate along expansion direction. As to friction resistant force especially means the force occurred on the interface of paste and aggregate along the orthogonal direction of expansion direction. Therefore, we can know that the resistant force along the expansion direction is the summation of friction and normal force (Fig.2). Based on this hypothesis, it was easy to imagine that the expansion strain of paste is larger than the expansion strain of mortar and the expansion strain of mortar is larger than the expansion strain of concrete. More clear explanation was expressed as following.



The resistant force along the expansion direction is the summation of friction and normal resistant force.

Fig.2 Mission of aggregate on the resistance of expansive concrete

Assuming the expansion of paste with the addition of expansive additive was A. Then, replace the paste by aggregate in the volume of 50% and the coarse aggregate was considered without expansion occurrence. Therefore, the theoretical expansion of concrete should be half expansion of the pure paste specimen, 0.5A. However, since the aggregate was uniformly distributed in the concrete specimen, paste could not expand freely, like pure paste specimen. Therefore, the expansion of expansive concrete was less than 0.5A and the role of aggregate in expansive concrete was regarded as one kind of resistance force for expansion (Fig.3).

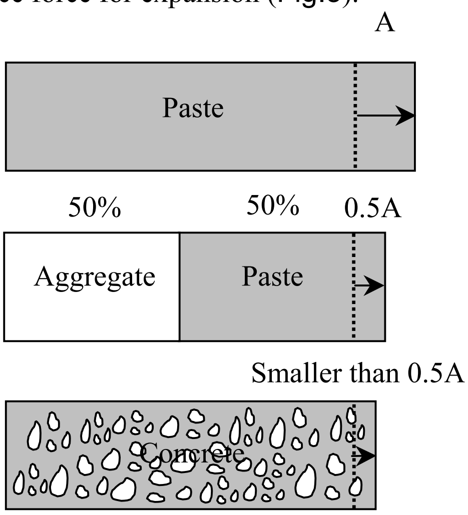


Fig.3 Mechanism of expansive concrete

3.2 Expansion tendency of SCC with expansive additive

As mentioned at beginning, in order to assure the passing ability of SCC, the amount of coarse aggregate was limited. That is to say that one difference between the concrete with the normal amount of coarse aggregate (hereafter, normal concrete) and SCC on mix proportion is the amount of coarse aggregate. To compare the expansion tendency of expansive additive on the application of concrete with the normal concrete and SCC, the expansion tendency was explained by varying the amount of coarse aggregate (Fig.4). Assuming the same composition of mortar was employed. Here same composition of mortar means water-to-cement ratio and the ratio of sand to mortar in volume (Vs/Vm) in mortar are same. Then replace the mortar by coarse aggregate in the volume of 50% and 30% for normal and SCC respectively and the theoretical expansion of normal concrete and SCC would be 0.5E and 0.7E. Besides due to the larger amount of coarse aggregate, expansion resistance of normal concrete was considered to be larger than SCC. Therefore, the discount level of normal concrete from the theoretical expansion was larger than SCC. Finally, it was easy to know that the expansion of SCC with the expansive additive was larger than that of normal concrete. That is to say that the expansion increased with the reducing of the amount of coarse aggregate.

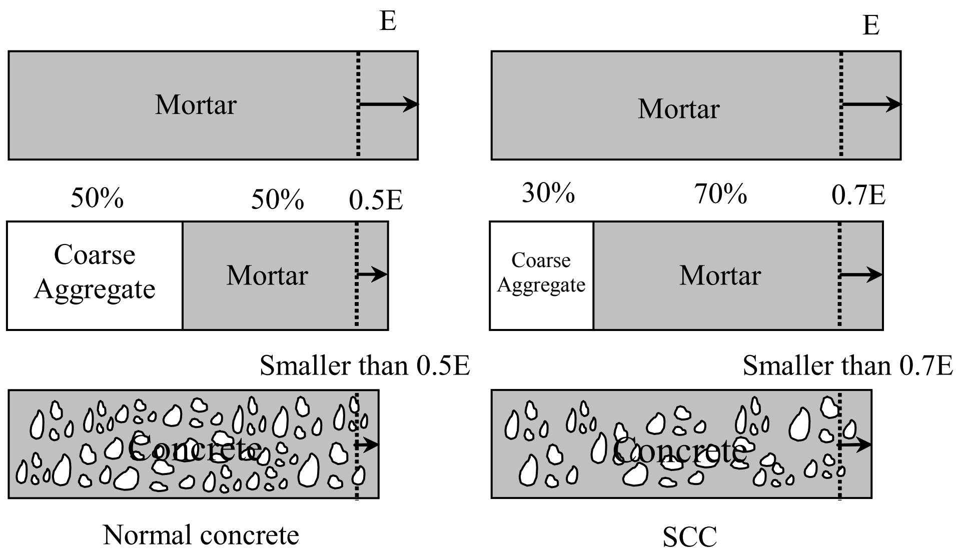


Fig.4 The influence of coarse aggregate on expansion of normal concrete and SCC

However, the experimental result showed the expansion strain increased with the increase of amount of coarse aggregate that was the opposite tendency with previous hypothesis (Fig.5). In order to prove the above hypothesis, the dispersion density of expansive additive in paste (E/E+C) was regarded as the key index of expansion. From the past research, it was revealed that the expansion increased with the employment of expansive additive [2]. Combining the restraint ideal of aggregate, it could be expressed by the Fig.6. If amount of coarse aggregate is fixed, expansion will increase with the increase of the dispersion density of expansive additive. If the dispersion density of expansive additive is fixed, expansion will reduce with the increase of coarse aggregate.

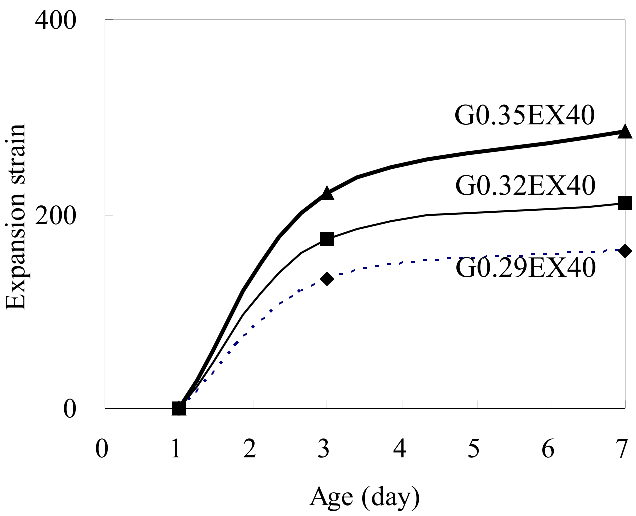


Fig.5 Relationship of expansion strain and age for different amount of coarse aggregate

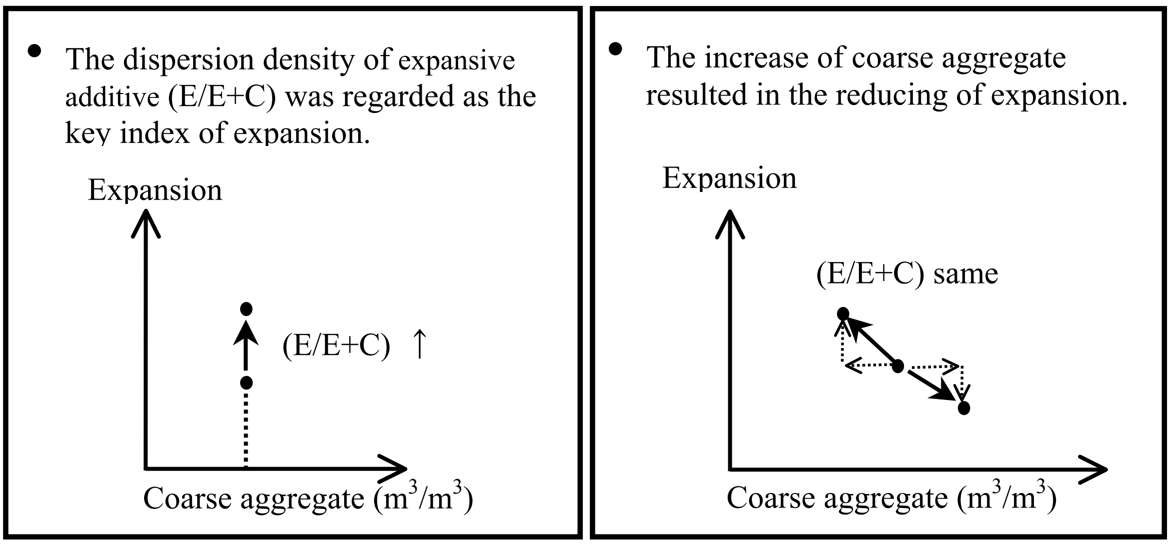


Fig.6 The influence of (E/E+C) on expansion with different amount of coarse aggregate

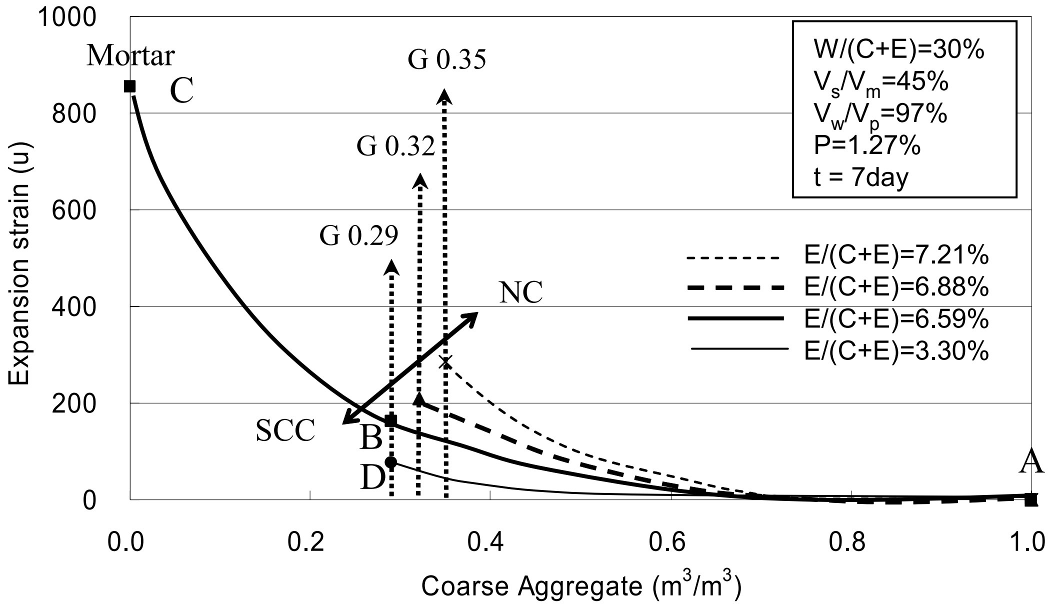


Fig.7 Relationship of expansion strain and the amount of coarse aggregate

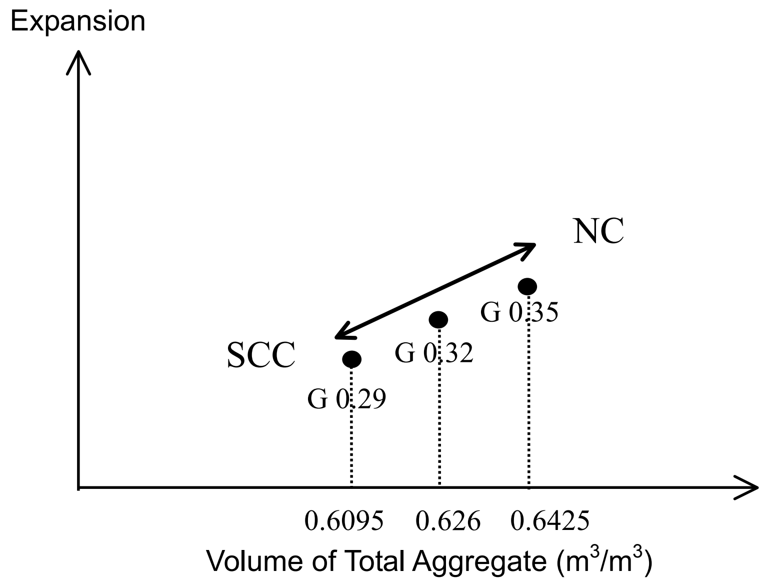


Fig.8 Relationship of expansion strain and the amount of total aggregate

In order to explain clearly, G0.29EX20 and mortar experiments were implemented as well. The mix proportion of G0.29EX20 was as same as G0.29EX40, only the amount of expansive additive was reduced from 40kg/m^3 to be 20kg/m^3. As the composition of the mortar in mortar experiment was designed as same as the other concrete mix proportion (Vs/Vm 45% and V_w/V_p=97%) and 40kg/m^3 of expansive additive was employed. The total results were showed in Fig.7 by changing the horizontal axis from age to be the absolute volume of coarse aggregate per 1m^3.

As shown in Fig.7, when the volume of coarse aggregate was equal to 1.0m^3/m^3, the expansion strain of concrete was assumed to be zero (A point). In the case of E/(C+E) equal to 6.59%, the relationship of expansion strain and coarse aggregate was represented as the curve composed by A, B and C point. And according to the previous explanation, as E/(C+E) equals to 6.59%, the theoretical expansion strain when coarse aggregate was equal to 0.29m^3/m^3 (B point) should be 71% of the mortar expansion (850μ) measured from the experiment, about 600 μ. (850μ*0.71=603.5μ) Since the mix proportion of G0.29EX40 was just the mortar replaced by 0.29 m^3/m^3 of coarse aggregate in the mortar mix proportion. That is to say that the mortar absolute volume of G0.29EX40 was $0.71m^3/m^3$. Therefore, the theoretical expansion of G0.29EX40 should be as same as 71% of pure mortar expansion strain when the distribution of coarse aggregate was not considered. However, the experimental result was less than 1/3 of the theoretical expansion which could prove that the resistant force of coarse aggregate was larger than fine aggregate. And the resistant mechanism of aggregate (the existence of normal resistant force) mentioned above was proved as well. Moreover, as the volume of coarse aggregate equal to $0.29m^3/m^3$, the expansion strain increased when E/(C+E) increased from 3.30% to 6.59% (D point to B point). Comparing the mixing proportion of D and B point, the only one difference was the density of expansive additive, E/(C+E). That was to say that the increase of E/(C+E) was the only reason to explain the increase of expansion strain. And it was revealed that the dispersion density of expansive additive to total powder (E/(C+E)) was positively proportional to expansion strain. From the experimental results, it was revealed that the expansion strain was reduced on the design direction of SCC (the reducing direction of the amount of coarse aggregate), if same weight of expansive additive was employed. Even the amount of total aggregate was considered, it still revealed the same tendency. (Fig.8)

In this paper, the mortar composition in all mix proportions was designed to be same (same V_s/V_m and V_w/V_p). Besides, since same materials (cement, sand and gravel) were employed, therefore the growth of Young's modulus (compressive strength) of mortar (paste) could be regarded as the same value. In the other words, the Young's modulus of mortar was not considered in this paper. However, as we know that Young's modulus growth of mortar is positively proportional to the compressive strength growth of mortar. In the case of same water-to-cement ratio (same compressive strength), due to the employment of low heat cement in SCC, Young's modulus (compressive strength) would gain slowly and some expansion of mortar may be restrained by coarse aggregate. This was considered to be the reason resulted in the small value on the expansion of SCC with the addition of expansive additive as well.

4. CONCLUSIONS

(1) Expansive concrete was divided as two parts (paste and aggregate). One is paste which was regarded as the expansive resource and the other is aggregate which was regarded as the resistance for expansion. And the resistant behaviour of aggregate on expansion was expressed by two types of force, including the friction and normal force which was depended on the size of aggregate. And this hypothesis was proved by the experimental result.

(2) As same weight of expansive additive was employed for SCC mix proportion with different amount of coarse aggregate, the expansion strain reduced with the reducing of coarse aggregate. This phenomenon was explained by the ratio of expansive additive to total powder, E/(C+E). Since as the volume of coarse aggregate reduced, the dispersion density of expansive additive in paste would be decreased as the same time. Therefore, though the amount of coarse aggregate reduced, the expansion strain still reduced. That is to say that the expansion of SCC using expansive additive was less than the case of conventional concrete with more amount of coarse aggregate. In another words, in order to get same expansion strain of conventional concrete, the amount of expansive additive was suggested to increase on the application of SCC.

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