Mechanical performance of expansive concrete in uniaxial tension test with different cement types, ages, and curing conditions

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ABSTRACT

Cracking is one of the most important problems in terms of concrete durability. Expansive additive is a promised countermeasure against cracking. Expansive additive gives volume expansion to concrete and it results in less autogenous shrinkage and drying shrinkage. When expansive additive more than normal content is used, chemical prestress is introduced to concrete if there is some restraint. However, it was reported that when expansive additive was used in massive concrete, which suffers high temperature history, the introduced prestress was lost after the temperature returned to the room temperature. This phenomenon is a serious problem for massive concrete with expansive additive, however, the mechanism is not clarified yet. The objective of this paper is to understand the performance of concrete with expansive additive which suffered high temperature history. Uniaxial tension test was conducted with concrete specimens changing cement type, testing age, and curing condition. The obtained results showed that, first, the effect of expansive additive, introduced prestress and prestrain is much different depending on cement type and curing condition. It was confirmed that even if chemical prestress was lost due to high temperature history, chemical prestrain is retained.

Keywords: Expansive additive, Chemical prestress, Chemical prestrain, High temperature,

1. EXPERIMENTAL METHODOLOGY

To examine how chemical prestress and prestrain change when cement type and curing temperature is different, uniaxial tension test was conducted. Concrete stress, rebar strain, and crack width were measured to assess the effect of expansive additive, introduction of prestress and suppression of cracks width. The test was conducted with universal testing machine under displacement control.

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Both ends of specimen were fixed with steel plate with double nuts to introduce enough restraint to the specimens, in other words, to introduce chemical prestress and chemical prestrain effectively. Concrete specimens measure 100mm×100mm×400mm, two strain gages were attached at center of D16 steel screw reinforcing bar, embedded in concrete specimen.

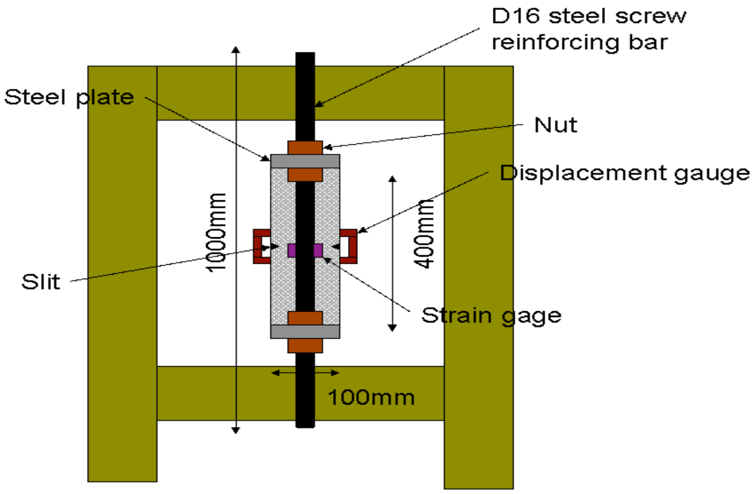

Figure1. Uniaxial stress test over

Table1: Concrete mix proportion

	W/B	air	W	C	E	S	G	AE
	%	%	(kg/m^3)					250ml/100kg
NE0	45	6	165	367	0	776	985	918
NE20	45	6	165	367	20	776	985	918
NE40	45	6	165	367	40	776	985	918
LE0	45	6	165	365	0	776	985	918
LE20	45	6	165	345	20	776	985	918
LE40	45	6	165	325	40	776	985	918
HE0	45	6	165	377	0	776	985	918
HE20	45	6	165	357	20	776	985	918
HE40	45	6	165	337	40	776	985	918

The setup of experiment is shown in Figure 1. Triangle slits of 1cm deep were prepared at the center of specimen to introduce cracks at center of specimens to measure rebar strain at crack. In this study, three types of cement were used: Ordinary portland cement (N), low-heat portland cement (L), and high early strength portland cement (H). The concrete mix proportion is shown in Table1 .The tests were conducted at the ages of 7 days and 28 days. All specimens were cured in temperature of 20 and humidity of 60%. Additional condition with high temperature (35±5°C) was applied for specimens with ordinary portland cement. Standard amount of expansive additive used in this research is $20kg/m^3$. In this research, $0kg/m^3$(E0), $20kg/m^3$(E20), and $40kg/m^3$(E40) of expansive additive were used. The specimens were demolded at 24 hours after mixing, and covered with wet cloth.

2. CALCULATION OF CHEMICAL PRESTRESS AND CHEMICAL PRESTRAIN

In this study, chemical prestress is obtained by subtracting cracking stress of concrete without expansive additive from that of concrete with expansive additive. Chemical prestrain is the strain difference between with and without expansive additive at $7N/mm^2$ after cracking.

3. EXPERIMENTAL RESULTS

3.1. Characteristic about introduction into Expansive concrete at high temperature of chemical prestress and chemical prestrain.

Chemical prestress and prestrain in uniaxial tension test of normal concrete at the age of 28 days are shown in Figure 2 and Figure 3, respectively. Figure 2 shows that large prestress is introduced in NE40 regardless of curing temperature. In contrast, NE20 shows negative prestress, in other word, tensile stress is introduced compared with concrete without expansive additive. NE20 with high temperature history shows larger negative prestress corresponding to the past reports. The tendency, less prestress in concrete with high temperature history, is same in NE40. On the other hand, as shown in Figure3, chemical prestrain of all concrete specimens show positive values. Specimen subjected to high temperature history has much larger prestrain than that in concrete cured under 20 degrees Celsius, particularly in NE20. These results show standard amount of expansive additive is difficult to introduce prestress under high temperature curing, however, even if chemical prestress is lost, chemical prestrestrain is retained. Generally, it is believed that chemical prestress and prestrain has the following relatioship.

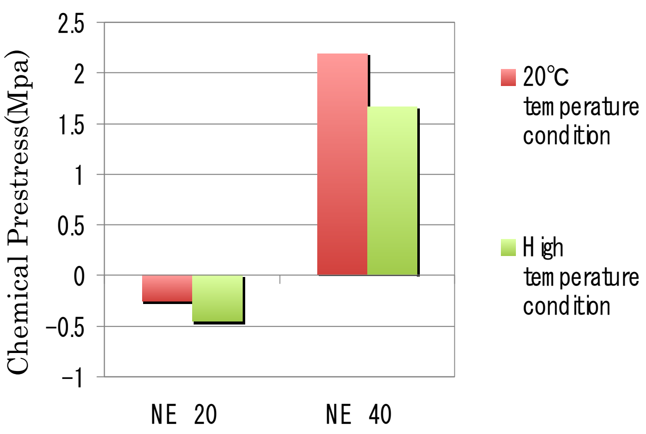

Figure2: Chemical prestress of normal concrete 28days age

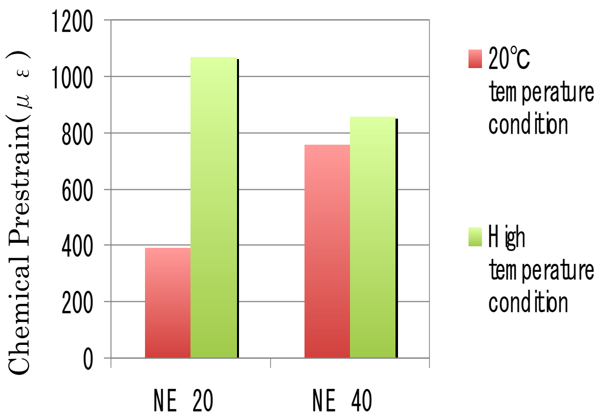

Figure3: Chemical prestrain of normal concrete 28days age

$$\sigma_{pre} = \frac{A_s}{A_c} \cdot E_s \cdot \varepsilon_{pre} \tag{1}$$

Here, σ_{pre}: prestress, A_s: Sectional area of rebar, A_c: sectional area of concrete, E_s: Young's modulus of rebar, and ε_{pre}: prestrain. The equation indicates that prestress is proportional to prestrain assuming that uniform prestress is introduced to concrete by the restraint of rebar. In reality, however, prestress in concrete is not uniform since hydration and expansion take place in parallel. One of the possible scenarios of large prestrain but small prestress will be as follows; The results in Figure 2 and Figure 3 indicate that at early stage of hydration, small amount of cement hydrates are pushed by reacted expansive additive to give prestrain to rebar. Prestress is introduced these hydrates. After that, large part of hydration takes place and they don't have any prestress.

3.2. Chemical prestress and prestrein in concrete with different cement type

Figure 4 and Figure 5 shows chemical prestress and chemical prestrain, respectively, of concrete with different cement types. In Figure 4, when standard amount of expansive additive, 20kg/m^3, is used, LE20 and HE20 shows larger prestress compared with NE20, normal cement. Concrete specimens with low-heat cement have the largest prestress. Chemical prestrain of the all specimens is positive, as shown in Figure 5. With 20kg/m^3 expansive additive, the magnitude of prestrain is similar regardless of cement type. Prestrains in concrete with 20kg/m^3 expansive additive is varied largely depending on cement type. The above results shows that in terms of prestress and prestrain, the combination of expansive additive and low-heat cement is the best.

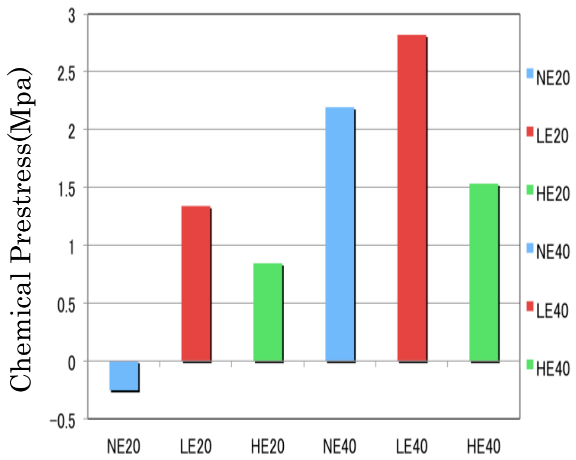

Figure4: Chemical prestress at 28days age (20 degree Celsius)

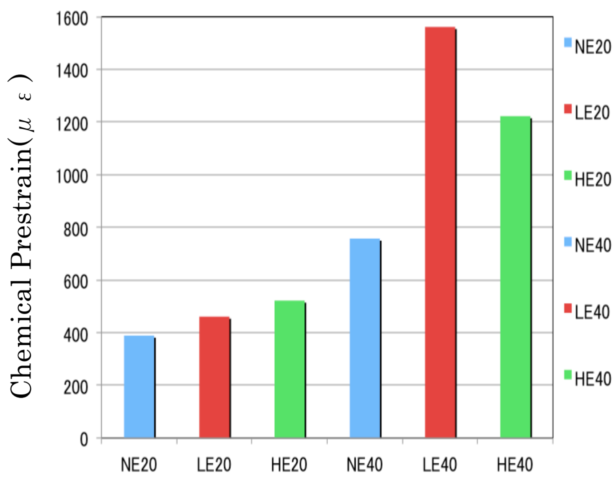

Figure5: Chemical prestrain at 28days age (20 degree Celsius)

4. CONCLUSIONS

The findings of this study are as follows:

Chemical prestress is hardly introduced when standard amount of expansive additive is used, perticularly under high temperature curing. However, even if chemical prestress is less or negative, chemical prestrestrain is introduced enough to reduce rebar strain. Introduced chemical prestress and chemical prestrain depend much on cement type of the concrete. The combination of expansive additive and low-heat cement is the best to introduce them.

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