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TENSILE CREEP OF FLY ASH CONCRETE AT EARLY AGE CONSIDERING THE YOUNG'S MODULUS DEVELOPMENT

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Tensile properties are important for predicting tensile stress which causes thermal cracking. Fly ash, a by-product from coal-fired power plants, has been recently used to reduce such thermal cracks. However, investigations dealing with tensile properties of fly ash concrete are still limited. This study focuses on the tensile properties of concrete mixed with fly ash at an early age. Fly ash was mixed in general purpose concrete with a cement-replacement ratio of 20% by mass to simulate fly ash concrete used in Japan. To examine tensile Young's modulus and tensile creep, direct tension test was conducted using dog-bone shaped specimens. The tensile creep tests were conducted at the age of 3 days or 7 days, and the loading (30% of splitting tensile strength at the loading age) was sustained for 14 days. Past investigations usually assumed a constant elastic strain during creep test. It should be noted however that elastic strain at early age decreases with the age of concrete as hydration continues. This study takes a consideration of Young's modulus development during creep test to distinguish actual creep and elastic strains. Test results show that creep strain has been underestimated when assuming constant elastic strain.

Keywords: Creep behavior, Thermal cracking, Creep strain, Elastic strain, Splitting tensile strength.

1 INTRODUCTION

Tensile properties, such as Young's modulus and creep, are required for estimating tensile stresses which cause thermal cracking. Creep, which is inelastic strain, is more severe under the influence of thermal stresses due to strains restraint. Fly ash (FA), a by-product from coal-fired power plants, has been recently used to reduce such thermal cracks. FA is generally replaced with cement, so that hydration heat which can cause thermal cracking is decreased.

In this study, the tensile creep tests using the dog-bone shaped specimen were conducted on FA concrete at the age of 3 or 7 days, and the loading was sustained for 14 days. The loading stress was constant during the tensile creep test and was set at 30% of the splitting tensile strength. It should be noted that elastic strain at an early age decreases with the age of concrete. However, the effect of the decrease in elastic strain during creep test has hardly been mentioned in most investigations (Benoît and Michel 1995, Matthieu *et al.* 2012). This study takes a consideration of Young's modulus development during creep test to distinguish actual creep and elastic strains based on superposition principle. In order to obtain the stiffness development during creep test, Young's modulus and elastic strain were examined at various ages. The elastic strains during the tensile creep test were also measured by temporary unloading.

2 EXPERIMENTAL PROGRAM

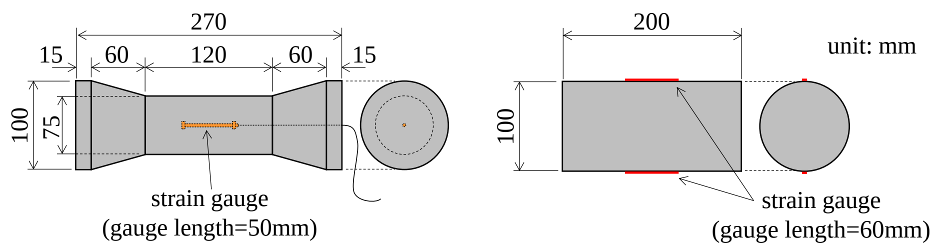
2.1 Materials and Specimens

The concrete materials and mixture proportions in this study are given in Table 1. Normal concrete with the water to cement ratio of 55% as shown in Table 1 is generally used for infrastructures in Japan. The amount of fly ash used in the present study was 20% by mass of the cement of the normal concrete. The targeted slump and the targeted air amount were 8 ± 2.5 cm and 4.5 ± 1.5%. The unburned carbon contained of FA decrease the effect of the AE water reducing agent, so the AE agent for restraint the influence of unburned carbon was mixed. In this study, tensile creep test for obtaining tensile creep, direct tension test for obtaining tensile Young's modulus, splitting tensile test (JIS A 1113 2006) for obtaining tensile strength, and compression test for obtaining Young's modulus were carried out.

Table 1. Concrete materials and mixture proportions.

Property	**Materials**	**Proportion (kg/m^3)**		**Density**
		Normal concrete	**FA concrete**	**(g/cm^3)**
Mix ID	---	N	FA	
Water (W)	Tap water	165	165	1.00
Cement (C)	Ordinary Portland cement	300	240	3.16
Fly ash (FA)	Class II	0	60	2.24
Fine aggregate (S)	Crashed sand	844	833	2.62
Coarse aggregate (G1)	Crashed stone 20-15 mm	499	493	2.67
Coarse aggregate (G2)	Crashed stone 15-5mm	499	493	2.67
Admixture (Ad1)	AE water reducing agent	3.00	2.40	1.07
Admixture (Ad2)[a]	AE agent for fly ash	0	16.8	1.04

[a] diluted solution (diluted 100 times with water)



(a) Dog-bone shaped specimen. (b) Cylindrical specimen.

Figure 1. Dog-bone shaped specimen and cylindrical specimen.

The dog-bone shaped specimen for the direct tension test and the tensile creep test is shown in Figure 1(a). A small mold strain gauge having a thermometric function was embedded at the center of the cross-section. A cylindrical specimen as shown in Figure 1(b) was used for splitting tensile test and compression test. Strain gauge was attached at the center of both side faces of each specimen for compression test. After casting, all specimens were carried into a curing room to be cured at a room temperature of 20 ± 1°C for 24 hours before demolding. After that, the specimens were cured underwater in a water tank (16 ± 1°C) installed in the curing room until load tests were to be carried out at the age of 3 days or 7 days.

2.2 Test Method

The test setup of the tensile creep test in the present study is shown in Figure 2. A weight was placed on the tip of the steel arm for loading. The relationship between the weight and the load stress was obtained beforehand, so the load cell was not used in this test. The loading apparatus was installed in the water tank in the curing room (room temperature = 20 ± 1°C). The water temperature was kept at 16 ± 1°C. In this study, the tensile creep test was conducted in water in order to eliminate the influence of drying.

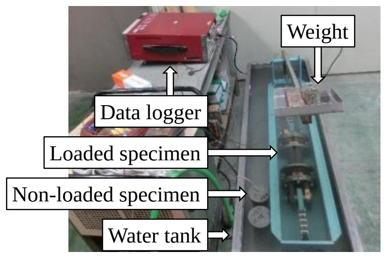


Figure 2. Test setup of the tensile creep test.

The non-loaded specimen was placed in the same tank. The strain of the non-loaded specimen was subtracted from that of the loaded specimen, so strains caused by factors other than loading were removed as much as possible. Measurement was carried out at one-hour intervals by using a data logger. The measurement items were strain and temperature of the dog-bone shaped specimen and water temperature. Table 2 gives the details of the tensile creep test. The loading started at the age of 3 days, or 7 days, as it was found in a separate FEM analysis of a wall structure that thermal stress turned from compression to tension from 3 days to 7 days. Thermal cracks occur at the age of around 2 weeks, so the loading was sustained for 14 days. According to Davis-Granville's law, stress less than 1/3 of strength is proportional to creep strain, so the loading stress in this study was set to 30% of the splitting tensile strength at the loading-start age. The strain at temporary unloading was recorded in order to measure the elastic strain during the creep test, and the Young's modulus was examined at the ages given in Table 2.

Table 2. Details of tensile creep test.

I.D.	Concrete	Loading age	Measurement of Young's modulus	Measurement of elastic strain
N3a	N	3 days	3, 7, 10, 14 and 17 days	At starting and ending
N3b	N	3 days	3, 5, 7, 10, 14 and 17 days	Every day
N3c	N	3 days	3, 5, 7, 10, 14 and 17 days	Every day
N7	N	7 days	7, 9, 11, 14, 17 and 21 days	At starting and ending
FA3a	FA	3 days	3, 7, 10, 14 and 17 days	At starting and ending
FA3b	FA	3 days	3, 5, 7, 10 and 17 days	Every day
FA3c	FA	3 days	3, 5, 7, 10 and 17 days	Every day
FA7	FA	7 days	7, 9, 11, 14, 17 and 21 days	At starting and ending

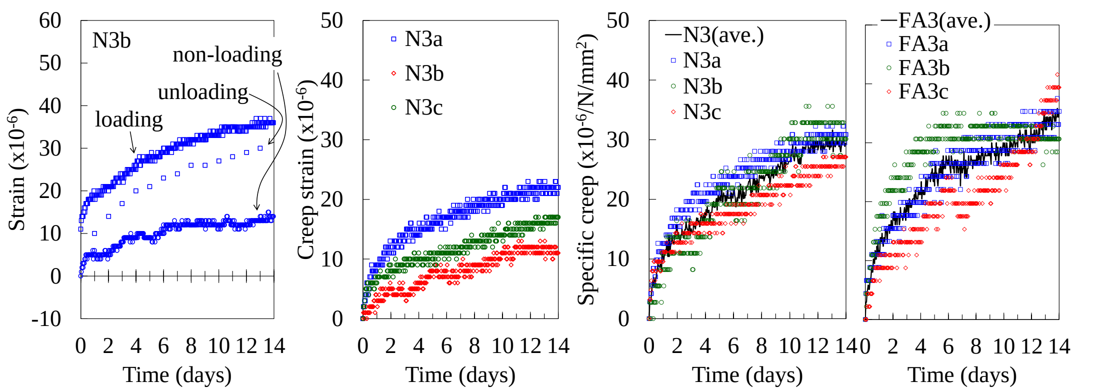
In determining the Young's modulus from the compression test, the cylindrical specimen was loaded using a universal testing machine until reaching the splitting tensile strength. The load and strain were recorded at every strain increment of 10 x 10^{-6}. After each recording, the load was temporarily removed and the strain at the unloading was measured. The Young's modulus was evaluated from the gradient of the regression line of the stress – strain relationship, which is linear at this loading range.

3 TEST RESULTS AND DISCUSSION

The splitting tensile strength at the loading age and the loading stress are given in Table 3. Each result is the average of the 3 test results. Figure 3(a) shows an example of the strain behavior of the loaded specimens and the non-loaded specimens. The data between the loading strain and non-loading strains are the strains at temporary unloading in order to measure the elastic strain during the tensile creep test. Creep strains as shown in Figure 3(b) were evaluated by subtracting the non-loading strain and the elastic strain from the loading strain, assuming that the elastic strain was constant at the start of the loading.

Table 3. Splitting tensile strength at loading-start age and loading stress.

I.D	**Splitting tensile strength *c***	**Loading stress (30% of f_t)**	**I.D.**	**Splitting tensile strength**	**Loading stress (30% of f_t)**
N3a	2.38 N/mm^2	0.714 N/mm^2	FA3a	1.51 N/mm^2	0.453 N/mm^2
N3b	1.22 N/mm^2	0.366 N/mm^2	FA3b	1.52 N/mm^2	0.456 N/mm^2
N3c	2.09 N/mm^2	0.627 N/mm^2	FA3c	1.52 N/mm^2	0.456 N/mm^2
N7	3.11 N/mm^2	0.933 N/mm^2	FA7	2.74 N/mm^2	0.822 N/mm^2



(a) Measured strain (b) creep strain (c) Specific creep (N) (d) Specific creep (FA)

Figure 3. Strain behavior based on constant elastic strain.

The loading stress of N3a was approximately twice that of N3b, so the creep strain of N3a was more than twice that of N3b. The specific creep of normal concrete obtained by dividing the creep strain by the loading stress is shown in Figure 3(c). In Figure 3(c), the average of the 3 results is also demonstrated. The difference in the specific creep of the normal concrete became smaller than the difference in the creep strain. The average specific creep was in the range of ± 6 x 10^{-6}/N/mm^2. The average specific creep of the FA concrete had larger errors than that of the normal concrete and was in the range of ±10 x 10^{-6}/N/mm^2.

It should be noted that the elastic strain at early age decreases as the concrete age increases. The Young's modulus obtained from the tensile creep test is shown in Figure 4. The development of the Young's modulus of FA concrete is more gradual than the development of the Young's modulus of the normal concrete.

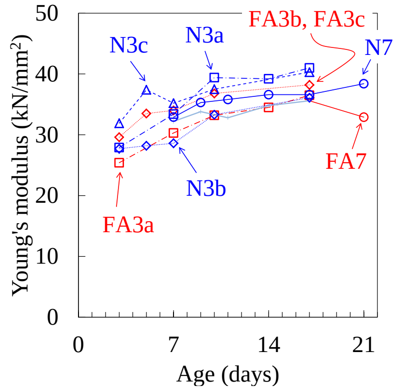


Figure 4. Young’s modulus during the tensile creep test

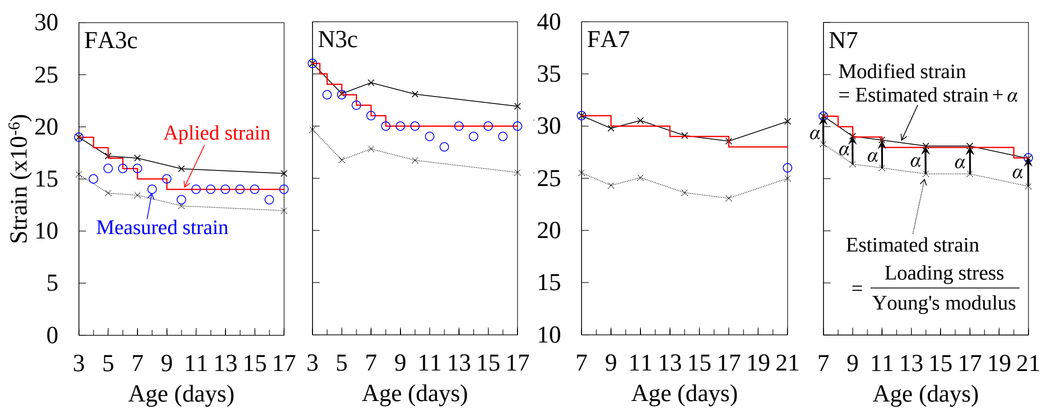


Figure 5. Decreasing elastic strains during the tensile creep test.

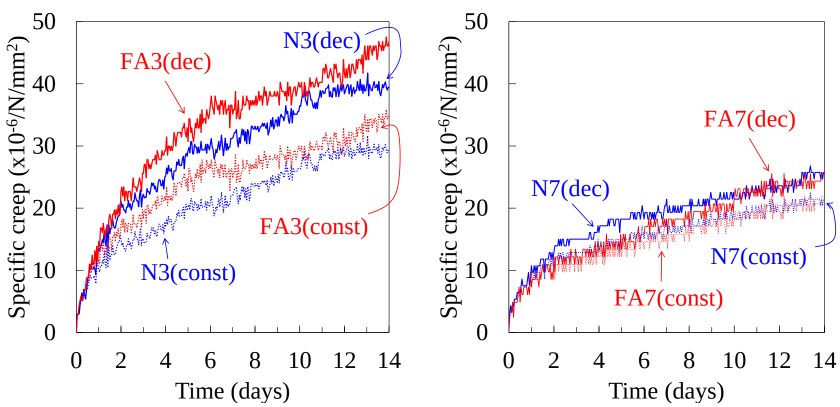


Figure 6. Specific creep based on the decreasing elastic strain.

Two sets of elastic strains were evaluated, one was from the measurement during the tensile creep test, and the other was estimated by dividing the loading stress to the Young’ modulus based on the Hooke’s Law, as shown in Figure 5. The estimated strains at the start of the loading were not equal to the elastic strains from the measurement. The modified strains were thus calculated by adding the difference (α) between the estimated strain and the measured strain at the start of the loading to the estimated strain. Both the measured strains and the modified strains were decreased with increasing ages. This result indicates that the creep determined from assuming a constant elastic strain has been underestimated. The modified strain of N7 was equivalent to the measured strain at the end of loading (at the age of 21 days). However, the modified strains such as FA3c and N3c had a different behavior with the measured strains during the tensile creep test. The elastic strains, shown as red lines in Figure 5, for evaluating the creep in this study were therefore determined with reference to the measured strains rather than the modified strains. It can be seen that the applied strains of FA3c and N3c decreased until the age of 8 or 9 days, while the elastic strains of FA7 and N7 decreased more gradually.

Figure 6 shows the specific creep based on the decreasing elastic strains. The dotted lines in Figure 6 represent the results when using the constant elastic strain. In the case when the load started at the age of 3 days, the difference in the specific creep caused by considering the development of the Young's modulus expanded with decreasing the elastic strain. In this case, the maximum increase of the specific creep of the normal concrete was $10.1 \times 10^{-6}/\text{N/mm}^2$, and was $8.0 \times 10^{-6}/\text{N/mm}^2$ on average. The FA concrete also had the specific creep's maximum increase of $11.7 \times 10^{-6}/\text{N/mm}^2$, and $8.4 \times 10^{-6}/\text{N/mm}^2$ on average. Such increase was larger than the difference in the specific creep caused by mixing FA into the normal concrete. In other words, the decrease of the elastic strain contributes more in the evaluation of the specific creep than the use of the FA mixing. On the other hands, the specific creep when starting the load at the age of 7 days was less affected by the FA mixing and the decreasing elastic strain than by starting the load at the age of 3 days.

4 CONCLUSIONS

This paper describes experimental investigations for obtaining development of the Young's modulus and tensile creep behavior at early age. Tensile creep behavior based on decreasing elastic modulus during creep test was examined. The conclusions of this paper are as follows:

(i) When loading started at the age of 3 days, the elastic strain determined by referring to the measured strain or the estimated strain decreases until the age of 8 or 9 days. This result indicates that the assumption of a constant elastic strain causes the underestimation of a specific creep.

(ii) The decrease in the elastic strain contributes more to the specific creep when loading started at the age of 3 days than the use of FA mixing. The specific creep when loading started at the age of 7 days was less affected by the FA mixing and the decreasing elastic strain.

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