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EFFECT ON CREEP IN TENSILE FAILURE OF EARLY AGE CONCRETE

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ABSTRUCT

The effects of stress-strength ratio and loading age on the tensile creep of concrete at early ages are elucidated on the basis of tensile creep experiments. Furthermore, effects of creep strain to failure are assessed by experiments. It is noted that the effects of stress-strength ratio are significant. It is concluded that capacity of tensile strain after loading is effected by loading age and stress and strength ratio. The results show that the strain capacity loaded at early ages is larger than others.

KEY WORDS

tensile creep, early age, stress- strength ratio ,creep failure

INTRODUCTION

This study has been carried out for rising accuracy of thermal stress analysis due to hydration heat of cement. The authors have already presented results of experimental creep studies of concrete at early ages, such as compressive creep [1] and creep during the unloading process [2]. They have also described a creep model [3] which is applicable to the prediction of thermal stress. Further, they have shown [4] the difference between compressive and tensile creep based on experiments at the same condition. In this paper, the effects of loading age and stress and strength ratio on tensile creep are investigated with the aim of presenting experimental data of tensile creep. An additional investigation is carried out on the effect of creep strain on tensile failure, in order to assess the effect of creep on cracking.

PROCEDURE OF TENSILE CREEP EXPERIMENTS

Procedure of tensile creep test is not defined in any standard. The method described in this paper is developed in the series of experiments. A dog-bone specimen is improved in order to observe creep failure and a embedded strain-meter is improved for dog-bone specimen.

The mix proportion used for this experiment was selected from candidates commonly used in actual reinforced concrete work in NAGOYA and it has a compressive strength of used 30N/mm^2, a water cement ratio of 40%, and a sand ratio of 44.6%. The mix proportion is illustrated in TABLE 1. Concrete was mixed in a temperature controlled laboratory at 20℃ and cast in molds before storage under the same conditions for 24 hours. Specimens were then demolded and immediately sealed with an aluminum membrane in order to avoid diffusion of moisture. Specimen were cured in a temperature - and moisture - controlled room at 30 ℃ and 98% RH until loading, which took place at 1 to 7 days.

TABLE 1 MIX-PROPORTION

Slump (cm)	Air (%)	W/C (%)	s/a (%)	Unit weigh (kg/m^3)				
				W	C	S	G	AD
8.0	4.0	55.0	44.6	172	313	787	1015	1.16

The creep test apparatus was of lever type with a temperature and humidity controlled enclosure in the loading area [1]. Humidity of every case was controlled at 98%. The strain of an unloaded specimen made under the same condition was measured in order to compensate for shrinkage not caused by creep, such as automogenous shrinkage so on. Creep strain is calculated by extracting the measured strain of the unloaded specimen from the strain of the loaded specimen. Tensile strength at the loading age, which was needed to calculate the stress-strength ratio, was measured by a splitting test on an unloaded specimen cured under the same conditions as the loaded ones.

Loading was by pulling on the attachments fixed to top and bottom of a specimen. Although this creep test apparatus is able to directly apply tensile stress by means of a lever, but a bending moment might be generated due to shifting of the loading axis from the center of the specimen due to creep deformation. An automatic adjusting system was added to compensate for this effect. Since the embedded bolts or epoxy resin for the pulling attachment might lead to failure at surface of the attachment at early ages, such as 1 day, and at high stress-strength ratios such as 60%, a dog bone specimen was better for such experiments. Dog-bone specimen is shown in Fig.1.

Embedded strain meters modified to take measurements of concrete at early ages were

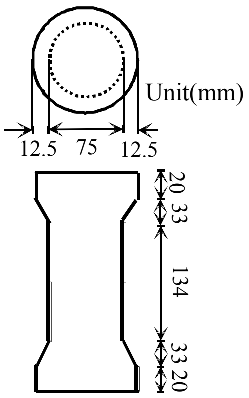

Fig.1 Dog-Bone Typed Specimen

TABLE 2 CASES OF THE EXPRIMENTS

Case No.	Loading age (day)	S/S (%)	Curing temp (℃).	Loading temp. (℃).
1	1	10	30	30
2	1	20	30	30
3	1	40	30	30
4	1	60	30	30
5	1	70	30	30
6	3	20	30	30
7	3	40	30	30
8	3	50	30	30
9	3	60	30	30
10	3	70	30	30
11	5	20	30	30
12	5	40	30	30
13	5	50	30	30
14	5	60	30	30
15	5	70	30	30
16	7	20	30	30
17	7	40	30	30

used for creep strain. Since the center section of the dog bone specimens is only 75 mm in diameter, the meter was improved to a more slender type in this case.

The experimental cases are shown in TABLE 2. The effect of stress-strength ratio (S/S) was investigated in cases 1 to 17. The loading period was basically 5 days.

EXPERIMENTAL RESULTS AND DISCUSSION

Tensile Creep

The relationships between creep strain with loading at 1 day, 3 days, and 5 days for several S/S value are shown in Figs.2~4. Although creep strain increased significantly for the 3 days after loading, it reached a steady state at 5 days. The loading period was chosen to be 5 days in this study, since creep strain at early ages is affected significantly by several factors during this period. Creep strain at early period immediately increases after loading and its increment is significant as at an early age and at high stress-strength ratio. The relationship between stress-strength ratio and final creep strain at several loading ages is shown in Fig. 5. No linear relationship passing through the zero point is obtained in Fig.5 up to S/S=40%. Creep strain at 1 day loading is larger than other ages at lower S/S values and the effect of S/S is not significant. Creep strain increases at 40% of S/S

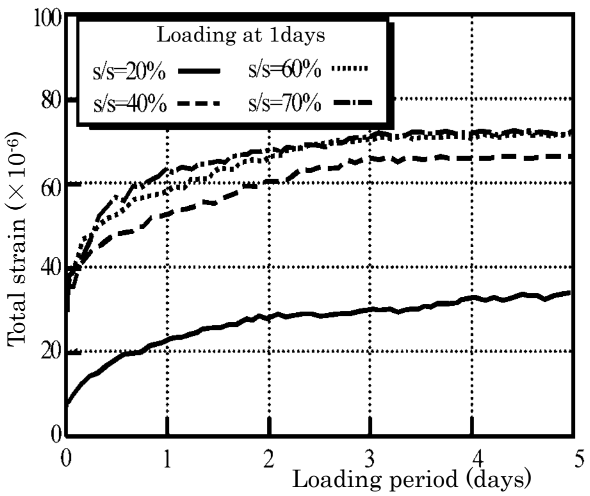

Fig.2 Effect of stress-strength

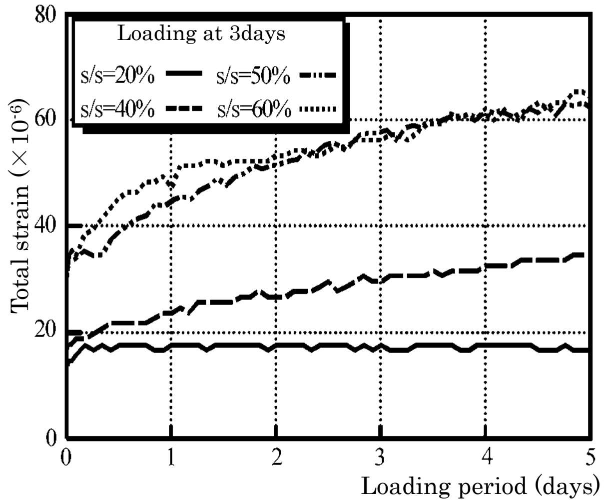

Fig.3 Effect of Stress-strength

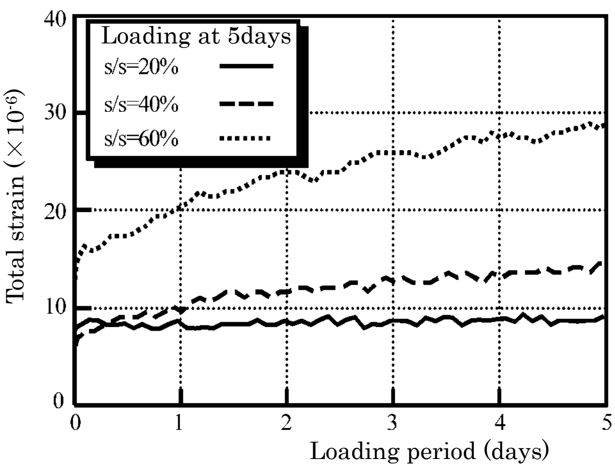

Fig.4 Effect of Stress-strength ratio

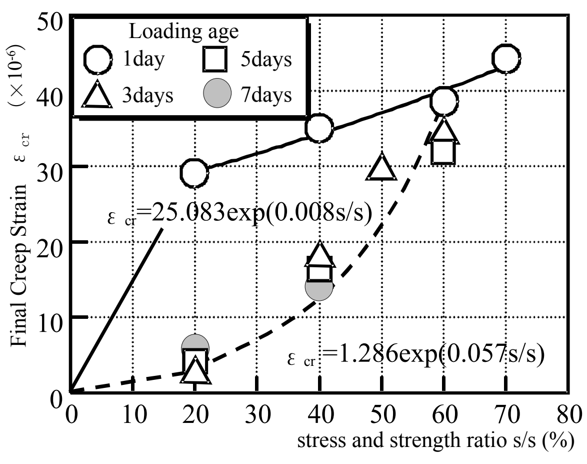

Fig.8 Stress-strength ratio and final creep strain

value in cases of loading at 3, 5, and 7 days. Final creep strain is strongly influenced by the stress-strength ratio in this study. Although tensile creep strain decreases with rising loading age, it is almost similar at other loading ages except 1 day in Fig.5. And the effect of loading age becomes smaller at higher S/S values in Fig.5. Loading stress increases with constant stress-strength ratio as loading age increases, since strength increases with age. Besides, creep decreases with rising loading age, since the matrix of cement paste hydrate becomes rigid as hydration progresses. The fall in creep strain with increasing loading age is nearly equal to the rise in loading stress due to hydration. This assertion is supported by Fig.6, in which the relationship between loading stress and final creep strain is shown for several loading ages. Relationship between loading age and final creep strain is shown in Fig. 7. The final creep strain decreases at greater loading ages in the case of loading at the same stress.

It can be concluded that factors which dominate the fall in tensile creep affect the rise in tensile strength as hydration progress and that both phenomena are caused by the rigidity of the cement paste matrix. Although the effect of loading age is insignificant at S/S values of more than 60%, the creep strain might reach to the deformation limit at these higher S/S ratios. It can be concluded that effect of deformation limit is more significant than effect of loading age. Creep failure might occur at such S/S ratios, if the stress were continuous. Although creep failure is described later, the possibility of creep failure is supported by the fact that tensile creep specimens failed within a day after loading at S/S=70% ~ 80%. The effect of stress-strength ratio at one day is smaller than at other loading ages and the final creep strain is smaller in this case.

Although creep strain is mainly generated by seepage of pore water of cement paste on compressive creep at a matured age, it is considered that creep strain is generated by defective zone and micro cracking at an early age due to weakness of cement paste. Since the results above mentioned show that large creep strain is generated with independence on stress-strength ratio in loading age of 1 day, defective zone might cause creep deformation upon tensile creep at an early age. The mechanism of tensile creep generation at one day is asserted slightly different from that at other ages.

Effect of creep strain on tensile failure

Creep strain is assumed to have no influence on steady tensile failure in thermal stress analysis, since it relaxes completely into constrained stress, such as thermal stress. However tensile creep might influence capacity of tensile strain, and this assumption is supported by observation of cracking at lower strain than 100 μ , which is ordinary tensile strain capacity, at continuous tensile loading.

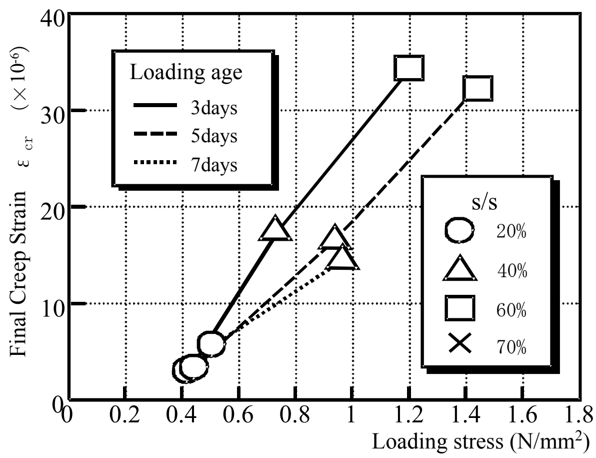

Fig.6 Loading stress and final creep strain

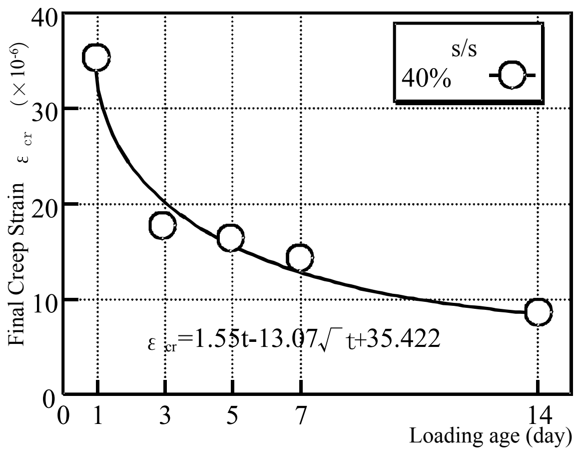

Fig.7 Loading age and final creep strain

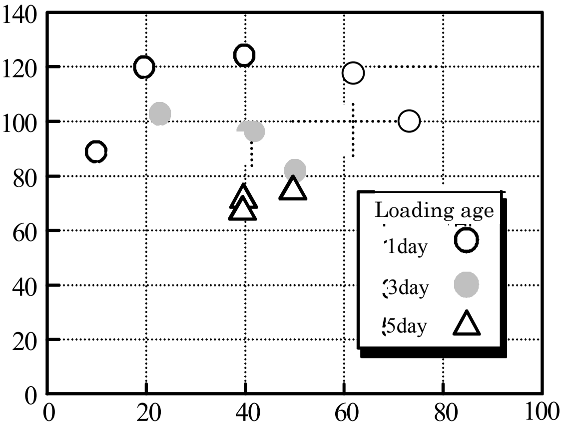

Fig.-8 Stress and strength ratio and strain capacity

Tensile failure tests were carried out by adding further stress after finishing the tensile creep tests in order to investigate the effect of creep strain on tensile failure.

Strain capacity after tensile creep test is defined as follows;

(strain capacity) = (total strain at failure) – (creep strain) –
(strain of unloaded specimen, consisting of automogenous shrinkage etc.) (1)

The relationship between strain capacity and stress-strength ratio in the creep tests is shown in Fig. 8. Regarding the effect of creep strain on the strain capacity, it should be noted that strain capacity is effected at higher S/S= 40%, although little effect is observed at less than 40%. And it is noted that significant decrement of strain capacity is observed at 70%. It can be pointed out that design tensile strain capacity should decreased by taking the effect of creep into account beyond S/S=40% from the results of this study. However, this effect hasn't been applied for prediction of cracking in thermal stress analysis. Specimens loaded at 1 day and 5 days with S/S = 80% failed in within 1 hour of adding all loads. Although it is considered that bending moment might be added by adjusting error of test apparatus, possibility of creep failure is not negligible. The relationship between strain capacity and generated creep strain is shown at each loading age in Fig.9. Although higher creep strain induces lower strain capacity in each loading

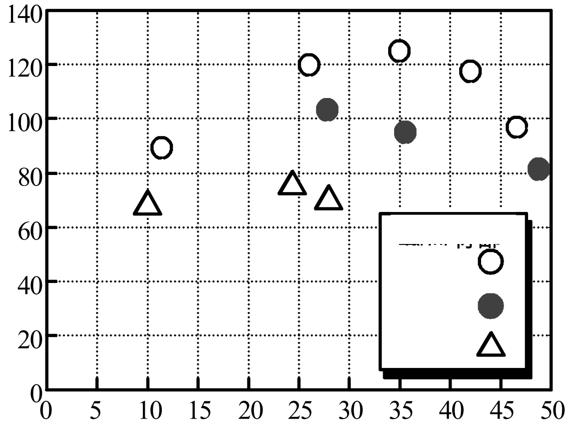

Fig.9 Creep strain and strain capacity

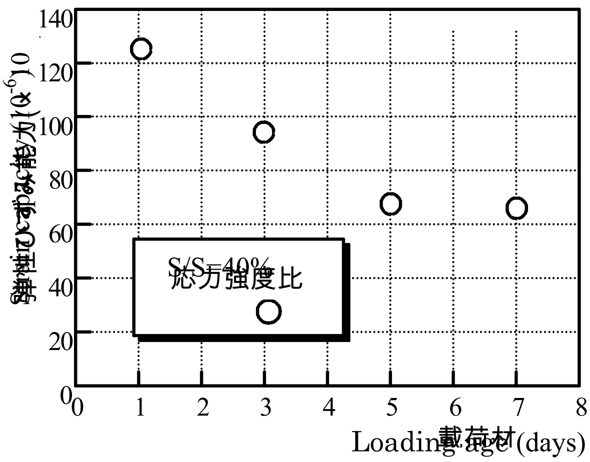

Fig.10 Loading age and strain capacity

age, no certain relationship is observed in investigation of all data. It is noted that strain capacity isn't effected by creep strain but by stress and strength ratio. This means that decrement of strain capacity is induced by generating defective zone at higher stress and strength ratio.

The relationship between strain capacity and loading age at S/S=40% is shown in Fig.10. It is noted that strain capacity decreased with rising of loading age. It seems to reach a stable value beyond 5 days, and the strain capacity after tensile creep at 5 days is approximate 60 μ . Although strain capacity of 1 day's loading is larger than others, which shows the highest creep strain due to generating defective zone, it is considered that healing at defective zone might be occurred corresponding to hydration at such a early age loading.

CONCLUSION

The results obtained in this study are described as follows.

1) The effects of stress-strength ratio on creep strain when loading takes place at 3 to 7 days of loading age are significant. No linear relationship was observed at low stress-strength ratios such as 20% ~40%. Creep strain significantly increased beyond S/S=60 %.
2) The creep strain with loading at 1 day is larger than that when loading takes place at 3 days ~ 7 days for low stress-strength ratios such as 20% ~40%. Furthers, the effects of stress-strength ratio with loading at 1 day are less significant than with loading at 3 ~7 days. It is considered that the creep strain with loading at 1 day is larger than in other cases, since micro cracking easily occurs due to weakness of the cement hydrate.
3) Tensile creep strain decreases at early age with loading age. However, this effect of loading age is smaller than that of stress-strength ratio.
4) Tensile strain capacity after creep test is effected by stress and strength ratio. Amount of effect is as small as early age loading.
5) Tensile creep strain induces little effect on tensile failure for S/S=20 ~ 40%. Certain effects can be observed in tensile failures at more than S/S=40 %, such as decreasing strain capacity to failure at high stress-strength ratio.

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