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EXPERIMENTAL STUDY ON COMPRESSIVE YOUNG'S MODULI AND TENSILE YOUNG'S MODULUS OF FLY ASH CONCRETE

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Initial cracks due to volume changes at an early age affect the durability of concrete structures, so numerical simulations are often conducted in order to predict cracks. Such prediction requires some mechanical properties of early age concrete. Tensile Young's modulus is directly dependent on the prediction of tensile stress and is one of the important input data for FEM analysis. However, direct tension test for tensile Young's modulus needs a unique apparatus and specimen, and such test is not suitable for evaluating Young's modulus at early ages of concrete. The present study compared tensile Young's modulus with compressive Young's moduli of Fly ash concrete. Compressive Young's moduli used in this study were secant modulus and initial tangent modulus. In addition, linear modulus taken from a regression line of a compressive stress-strain curve in the range of stresses less than the splitting tensile strength was also evaluated. It is found that the secant modulus, which is generally used as Young's modulus in Japan was clearly smaller than the tensile Young's modulus, which means that, tensile stresses evaluated using a secant modulus might be underestimated. On the other hand, linear modulus and initial tangent modulus were almost equal to the tensile Young's modulus. This result indicates that tensile stresses can be evaluated using Young's modulus obtained from a compression test with general apparatus and specimens.

Keywords: Direct tension test, Linear regression, Secant modulus, Splitting tensile strength.

1 INTRODUCTION

It is well known that cracking due to volume change at an early age are undesirable for the durability of concrete structures. Numerical simulations are often performed in order to predict thermal cracking. Tensile properties, such as Young's modulus and creep, are required for an estimation of tensile stress, which causes thermal cracking. Tensile Young's modulus is directly dependent on the prediction of tensile stress and is one of the important input data for FEM analysis. Young's modulus in Japan is generally a secant modulus obtained from a compression test. Mimura *et al.* (2011) report that the tensile Young's modulus based on the direct tension test by using the slender reinforced concrete (RC) specimen is higher than the compressive modulus (secant modulus) at early age. In this study, several Young's moduli obtained from compression test, which can be performed with general equipment, were compared with the tensile Young's modulus obtained from the direct tension test by using the unique apparatus and specimen. Compressive Young's moduli in the present study were secant modulus and initial tangent modulus. In addition, linear modulus, which is taken from a regression line of a compressive stress-strain curve in the range of stresses less than the splitting tensile strength was also evaluated.

2 EXPERIMENTAL PROGRAM

2.1 Materials and Specimens

The concrete materials and mixture proportion in this study are given in Table 1 and Table 2, respectively. The amount of fly ash (FA) used in the present study was 20% by mass of the cement of the normal concrete used for infrastructures in Japan. The targeted slump and the targeted air amount were 8 ± 2.5 cm and 4.5 ± 1.5%. The unburned carbon contained of FA decreases the effect of the air entrainment (AE) water reducing agent, so the AE agent for restraining the influence of unburned carbon was used in FA mixes. In this study, 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.

Concrete materials	Type	Density
Water (W)	Tap water	1.00 g/cm^3
Cement (C)	Ordinary Portland cement	3.16 g/cm^3
Fly ash (FA)	Class II	2.24 g/cm^3
Fine aggregate (S)	Crashed sand	2.62 g/cm^3
Coarse aggregate (G1)	Crashed stone 20-15 mm	2.67 g/cm^3
Coarse aggregate (G2)	Crashed stone 15-5mm	2.67 g/cm^3
Admixture (Ad1)	AE water reducing agent	1.07 g/cm^3
Admixture (Ad2)	AE agent for fly ash	1.04 g/cm^3

Table 2. Mixture proportion.

	W/B [a]	W	C	FA	S	G1	G2	Ad1	Ad2 [b]
FA concrete	55%	165	240	60	833	493	493	2.40	16.8

[a] Water-binder ratio (B=C+FA), [b] diluted solution (diluted 100 times with water)

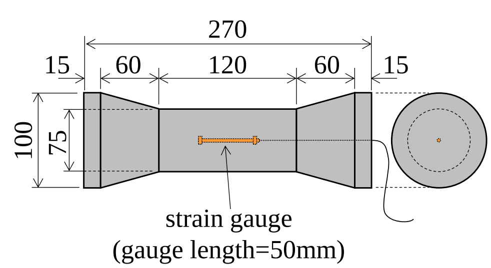

Figure 1. Dog-bone-shaped specimen for direct tension test.

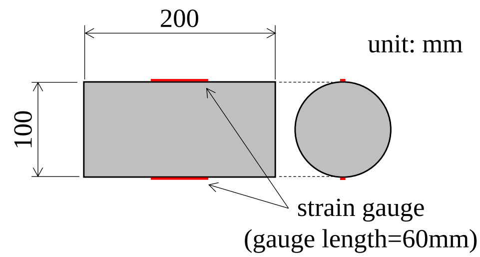

Figure 2. Cylindrical specimen for splitting tensile strength test and compression test.

The dog-bone shaped specimen for the direct tension test is shown in Figure 1. A small mold strain gauge, having a thermometric function and gauge length of 50 mm, was embedded in the center of the cross-section of the specimen. A cylindrical specimen with a diameter of 100 mm and a height of 200 mm as shown in Figure 2 was used for splitting tensile test and compression test. Strain gauge with gauge length of 60 mm was attached at the center of both side faces of each specimen for compression test. After casting concrete, all specimens were carried into the curing room to be cured at a room temperature of 20 ± 1 ^{o}C for 24 hours before demolding. After that, the specimens were cured underwater in a tank installed in the curing room until load tests were to be carried out at the age of 7 days. Water temperature in the tank was 16 ± 1 ^{o}C.

2.2 Test Method

In this investigation, Young's moduli evaluated by several procedures, based on data obtained from the direct tension test and compression test, were compared. The direct tension test by using a dog-bone shaped specimen and a loading apparatus is shown in Figure 3 was carried out in order to obtain a tensile Young’s modulus. The load was manually applied to the tip of the steel arm. The specimen was loaded until its failure. The load and strain were recorded at every step of strain increment of 10×10^{-6}. After each recording, the load was temporarily removed and the strain at unloading was measured. Such loading/unloading cycle was performed twice at each strain level. The reason for this loading procedure is to eliminate the influence of inelastic strain as much as possible for the Young's modulus.

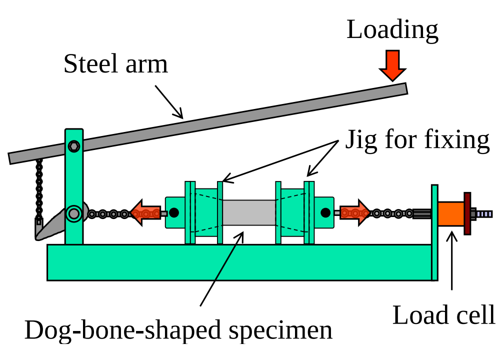

Figure 3. Test setup of the direct tensile test.

Compression test based on JIS A 1149 (2010) with a cylindrical specimen (diameter of 100 mm and height of 200 mm) was also conducted for obtaining a compression Young's modulus, as shown in Figure 4. The load and strain were recorded at every load increment of 10 kN. The specimen was loaded until its failure. The general compressive Young's modulus (hereinafter referred to as secant modulus) was evaluated from the data at the strain of 50 x 10^{-6} and the data at the load of 1/3 of the maximum load. In addition to compression test based on JIS, the compression test with the same procedure of the direct tension test, repeating loading and unloading, was also conducted. In this compression test, the loading ended after the stress corresponding to the splitting tensile strength was recorded. Thereafter, the same specimen for this compression test was used to perform a compression test based on JIS described above. In this investigation, the direct tension test and compression test by using specimens with FA concrete at the age of 7 days; four specimens were used for each test.

Figure 4. Test setup of the compression test.

3 TEST RESULTS AND DISCUSSION

Figure 5 shows an example of the stress-strain relationship obtained from the direct tension test. The strain shown in Figure 5 does not include the residual strain at unloading. The stress-strain relationship was almost linear up to the maximum point, as shown in Figure 5, so the gradient of the regression line was taken as tensile Young's modulus.

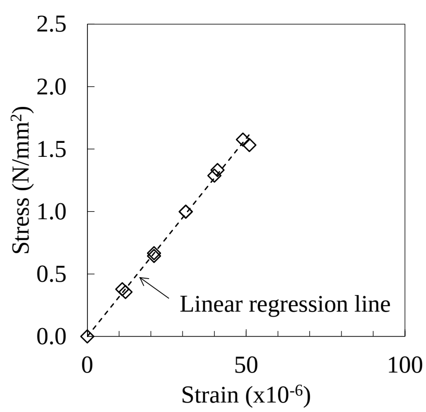

Figure 5. Stress-strain relationship of the direct tensile test.

Figure 6 presents the result of the compression test with the same procedure of the direct tension test. The f_t in Figure 6 means the splitting tensile strength. One of the compressive Young's modulus in this study (hereinafter referred to as linear modulus) was obtained from the slope of this linear regression line. The result of the compression test based on JIS is demonstrated in Figure 7.

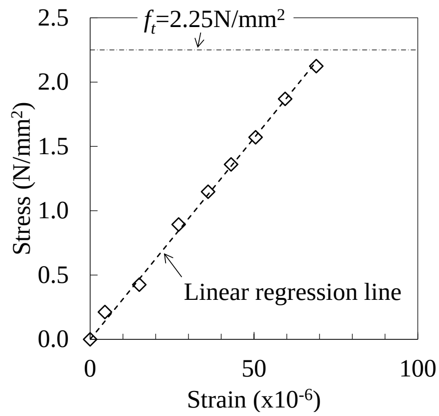

Figure 6. Stress-strain relationship of compression test with the same procedure of the direct tensile test.

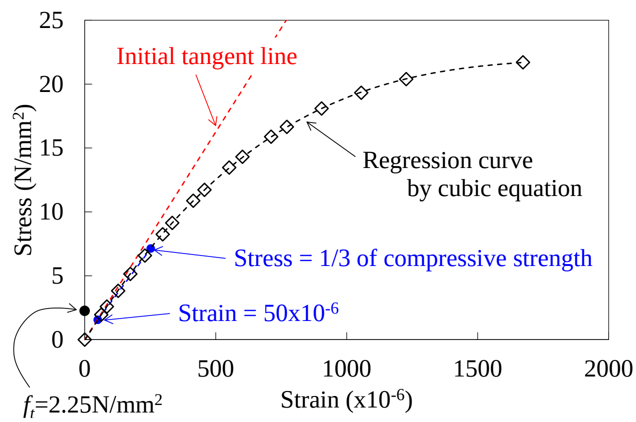

Figure 7. Stress-strain relationship of the compression test based on JIS.

Table 3. Results of Young's modulus

	No.1	No.2	No.3	No.4	Ave.
Tensile Young's modulus (kN/mm^2)	31.7	30.3	32.2	33.5	31.9 (1.00)
Secant modulus (kN/mm^2)	27.8	26.5	27.6	29.4	27.8 (0.87)
Initial tangent modulus (kN/mm^2)	32.5	31.4	32.5	34.4	32.7 (1.03)
Linear modulus (kN/mm^2)	29.6	31.7	31.3	33.5	31.5 (0.99)

The result in Figure 7 was regressed by the cubic equation shown in Eq. (1).

$$\sigma = a \cdot \varepsilon^3 + b \cdot \varepsilon^2 + c \cdot \varepsilon \quad (1)$$

where σ is stress (N/mm^2), ε is strain (x 10^{-6}), a, b and c are coefficients.

The experimental data was accurately regressed by the cubic curve in Eq. (1), and R^2 was more than 0.99. The coefficient c in Eq. (1) regresses the stress-strain relationship, which corresponds to the initial tangent modulus. The secant modulus, applied as a general compressive Young's modulus of concrete in Japan, was evaluated from the data at the strain of 50 x 10^{-6} and the data at the stress of 1/3 of the compressive strength, as shown in Figure 7. Table 3 gives the results of the tensile Young's modulus, the secant modulus, the initial tangent modulus, and the linear modulus. The numerical values in brackets () in Table 3 represent the ratio of each Young's modulus to the tensile Young's modulus. The secant modulus was obviously smaller than the tensile Young's modulus, with the average value being 87% of the tensile Young's modulus. This result indicates that tensile stresses evaluated using a secant modulus might be underestimated. On the other hands, the initial tangent modulus and the linear modulus were nearly equal to the tensile Young's modulus. This was because the stress-strain relationship shown in Figure 6 was almost linear in the stress range less than the tensile strength. However, the stress was not proportional to the strain as the stress increased, particularly beyond 1/3 of the compressive strength, as shown in Figure 7. Therefore, the difference between the tensile Young's modulus and the secant modulus can be caused by the difference in the level of the stress and strain used for the evaluation of the Young's modulus. In other words, the Young's modulus evaluated from the compressive stress-strain curve at the stress range less than the splitting tensile strength may be suitable for crack estimation even if the stress field differs. In addition, the loading apparatus and dog-bone shaped specimen used in the direct tensile test shown in Figure 1 and Figure 3 are not typical, so it is difficult to obtain the development evaluation of Young's modulus at early ages based on many tests. The compression tests by using a typical cylindrical specimen can be relatively easily performed at the various ages of concrete.

4 CONCLUSIONS

This paper describes experimental investigations for obtaining the development of Young's modulus at an early age for thermal crack prediction. For comparison with the tensile Young's modulus, several compressive Young' moduli were evaluated as the secant modulus generally used in Japan, the initial tangent modulus and the linear modulus obtained from the gradient of the regression line. The conclusions of this paper are as follows:

(i) The secant modulus was found smaller than the tensile Young's modulus, which was 87% in the present study. Therefore, tensile stresses evaluated using a secant modulus might be underestimated.

(ii) The tensile Young's modulus of FA concrete at the age of 7 days is almost equal to the linear modulus evaluated with the compressive stress-strain curve at the stress range less than the splitting tensile strength.

(iii) The Young's modulus evaluated from the compressive stress-strain curve at the stress range less than the tensile strength may be suitable for crack estimation even if the stress field differs.

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