J Rec Const Resources 1(3)197-203(2013)
http://dx.doi.org/10.14190/JRCR.2013.1.3.197

Print ISSN : 2288-3320
Online ISSN : 2288-369X

Tensile and Compressive Creep Behaviors of Amorphous Steel Fiber-Reinforced Concrete

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(Received November 29, 2013 / Revised December 19, 2013 / Accepted December 23, 2013)

In this study, the creep behaviors of amorphous steel fiber-reinforced concrete were investigated. Two different types of tests were carried out to evaluate the effect of amorphous steel fibers on the creep of concrete: compressive creep test and tensile creep test. Fiber volume fractions used in the test were 0.2% and 0.4% for tensile specimens, and 0.2% and 0.3% for compressive specimens. Based on the test results, the addition of fiber volume fraction of 0.2% into concrete could significantly reduce both compressive and tensile creep.

Keywords : Amorphous steel fiber, Tensile and compressive creep, Reinforced concrete

1. Introduction

The study of deformation of concrete as time progresses under sustained stress or loading (called creep), is important for estimating the long–term service–state of concrete structures. The presence of creep in concrete induces increases in deflection, curvature, and in pre–stressed reinforced concrete members, the development of creep results in the reduction of structural cracking strength (Partov et al. 2011). Once creep deformation exceeds the allowable limitation, concrete structures could be broken down. Wafa (1990) and Myers et al. (2008) investigated that the addition of fibers into concrete could significantly improve compressive strength, tensile strength, flexural strength, toughness and cracking control. Studies of the creep of concrete with added fibers were also evaluated; however, there was no consensus on the action of fibers in concrete creep. Zhang (2003) and Chern et al. (1989) showed that the addition of fibers can reduce creep, whereas Velasco et al. (2008) showed that the addition of fibers in concrete results in higher creep.

Moreover, most of the studies focused on the creep of concrete concentrates on compressive creep; therefore, compressive creep was significantly investigated using a large amount of data. Meanwhile, experimental data on concrete creep under tension are very scarce. Tensile creep could play an important role in reducing the restrained shrinkage stress. When a concrete element is restrained, the appearance of tensile creep strain can counteract the shrinkage strain. Therefore, considering tensile creep precisely will improve the

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Table 1. Geometry and material properties of amorphous steel fibers

Length (mm)	Thickness (mm)	Width (mm)	Tensile strength (MPa)	Aspect ratio (L/D)	Material	Shape
30	0.024	1.6	1,700	1,250	Amorphous steel	Straight

Table 2. Concrete mix proportion

fck (MPa)	Slump (mm)	Air condition (%)	W/C (%)	S/a(1) (%)	Unit content (kg/m^3)				
					Water	Cement	Fine Agg.	Coarse Agg.	Admixture
27	120	4.5	50	48	178.2	356.4	764	897	0.25

(1) S/a = sand to aggregate ratio

cracking potential of concrete for the long -term.

In this study, compressive and tensile creep tests were carried out to investigate the effect of the addition of amorphous steel fibers (ASF) in concrete on concrete shrinkage cracking. A compressive creep test was carried out following the guidance specified in ASTM C512/C512M-10 (2010) and tensile specimens having similar configurations of those of Reinhardt et al. (2010). In the test, various fiber volume fractions of the fibers were used to investigate the variation of the characteristics of creep strain according to the fiber volume fraction. Based on the test results, the creep characteristics of the amorphous steel fiber-reinforced concrete were understood.

2. Experimental program

2.1 Materials

In this test, the use of amorphous steel fibers (ASF) was investigated. The fibers are made of an amorphous alloy of the Fe family with a specific mass of 7,850 kg/m^3. The amorphous steel fibers used were a straight shape type with a length of 30 mm and a thickness of 0.024 mm (aspect ratio = 1,250). The details of the dimension and material properties used in this test are presented in Table 1.

A normal Portland cement was used. A specific concrete mixture corresponding to concrete strength of 27 MPa was designed. The ratio between water and cement was 0.5; that of sand and stone aggregate to cement was 2.15 and 2.5, respectively. All the ratios were kept constant for all mixtures.

Table 3. Material properties

Materials	Material properties
Cement	Normal Portland cement
	Blaine fineness: 320m^2/kg
	Specific mass: 3,150kg/m^3
Fine aggregate (sand)	Surface dried specific gravity: 2,600kg/m^3
	Fineness modulus: 2.60
Coarse aggregate (stone)	Surface dried specific gravity: 2,690kg/m^3
Superplasticizer	Polycarboxylate
	Specific gravity: 1,050kg/m^3
	pH: 6.5

Table 4. Number of test specimens

Test types	Fiber volume fraction (%)			
	0 (plain)	0.2	0.3	0.4
Compressive strength	12	6	6	6
Splitting tensile strength	6	6	N.A.	6
Compressive creep	1	1	1	N.A.
Tensile creep	2	2	N.A.	2

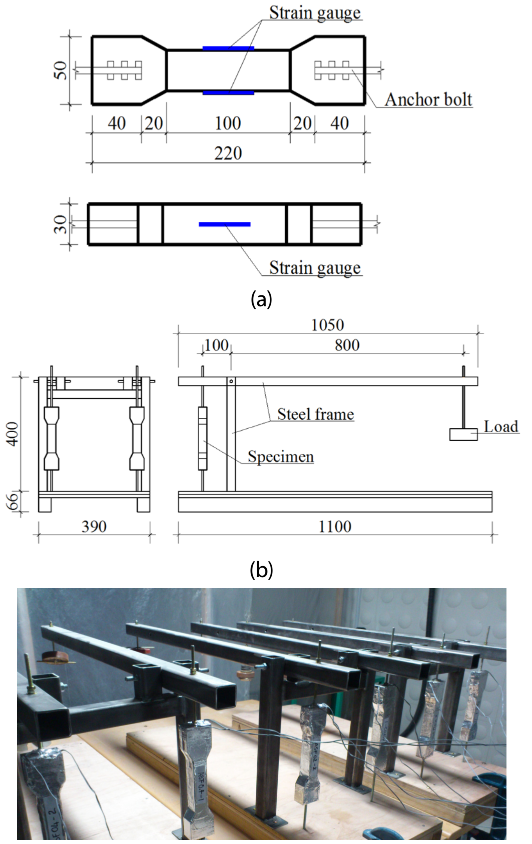
The details of concrete mix and material properties are presented in Table 2 and Table 3.

After casting, all the specimens were covered with 3 layers of plastic sheets to prevent moisture loss for 2 days in the case of tensile creep test specimens, and in the case of compressive creep test specimens this was 7 days.

The material strength was tested by compressive and splitting tests. The compressive strength of concrete was measured using the compressive test method specified in ASTM C39/C39M – 12a (2012), and the tensile strength of concrete was measured using the splitting tensile test method specified in ASTM C469/C469M – 11 (2011). In both tests, cylinders were used with the dimensions of 100 x 200 mm. In total, 48 specimens for compressive and splitting tensile strength tests were studied (Refer to Table 4).

2.2 Creep test specimens

In this study, two different types of creep test were used: compressive creep test and tensile creep test. The primary test parameter examined was fiber volume fraction (0%, 0.2%, 0.3%, and 0.4%). Plain concrete specimens were also used as control specimens. The number of test specimens for each fiber volume fraction added is presented in Table 4.



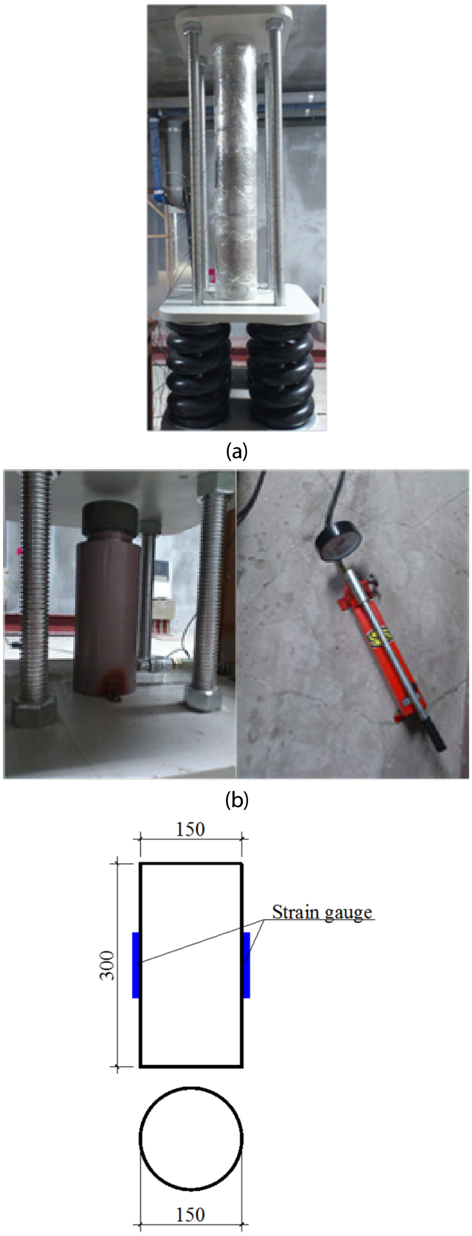
(a)

(b)

(c)

Fig. 1. Tensile creep test setup. a) Specimen geometry, b) Loading frame

The tensile creep test specimens were used that had similar configurations to those by Reinhardt et al. (2010). In this test, the specimens also had a dog-bone shape and were modified for use at a smaller scale. Steel anchors were embedded in concrete and connected to the loading frame using screw nuts. The details of the dimensions and configurations of test specimens are shown in Fig. 1. For each tensile creep test



(a)

(b)

(c)

Fig. 2. Compressive creep test setup. a) Test setup, b) Hydraulic pressure system, and c) Geometry of specimen

specimen, two strain gauges were attached at two opposite sides and at the middle along the longitudinal direction of the specimens to measure the strains of the specimens. The specimens were then sealed with 1 layer of aluminum to avoid sharp drying and Eigen-stresses in cross section.

The compressive creep test specimens were simpler in comparison to the tensile creep specimens. This test was performed according to the suggestion in ASTM C 512/512M–10 (2010). Compressive creep specimens were cylindrical in shape with a 150mm diameter and 300mm height. The details of dimension and test setup are shown in Fig. 2. For each compressive creep test specimen, two strain gauges were attached at the middle along the longitudinal direction of the specimens to measure the strains of the specimens. The specimens were then sealed with 3 layers of plastic to avoid sharp drying and Eigen-stresses in the cross section.

2.3 Test setup and measurements

The tensile creep test specimens were demolded on the second day of concrete age. The specimens were then cured at a temperature of 11±1℃ and a relative humidity of 55±10%. The temperature and relative humidity given in the standard of ASTM C 157/157M-08 (2008) were 23±2℃ and 50±4%, respectively. Thus, in comparison with the recommendation in ASTM C 157/157M–08 (2008), the temperature used in this test was less than the recommendation, while the relative humidity used in this test was almost the same.

The compressive creep test specimens was demolded on the 7th day after casting and were then cured at a temperature of 22±2℃ and a relative humidity of 85±10%. In comparison with the recommendation in ASTM C 157/157M-08 (2008) above, the temperature used in this test was almost the same, while the relative humidity used in this test was higher than that recommended.

Before all creep specimens were loaded, a data logger system was designed to acquire the strain data of specimens and the temperature and humidity from the strain gauges. In the case of the tensile creep test, the specimens were applied with a load of 5.5kN; in the case of the compressive specimens, the load was 5% of the designed compressive strength of concrete. The strain was measured immediately before and after loading, and the test data were set to be taken every 15 minutes.

3. Test results and discussion

3.1 Material strength

Table 5 shows the compressive strength, tensile strength, modulus of elasticity, and instantaneous elastic strain of concrete on the second day of concrete age. These values are in agreement with those of the tensile creep test.

Table 6 shows the compressive strength, modulus of elasticity, and instantaneous elastic strain of concrete on the 7th day of concrete age. These values are in agreement with those of the compressive creep test. The elastic modulus of concrete was calculated according to the suggestion in CEB-FIP 90 (1990). It can be seen that the addition of amorphous steel fibers contributes to significantly reduce both the compressive and tensile strength of concrete. The compressive strength of concrete is affected by the hydration of cement (Ghani et al. 2006) and the bond between fiber and aggregate, cement matrix (Tonoli et al. 2012, Bagherzadeh et al. 2012). At early age, the presence of fibers in concrete slowed the hydration of cement, and the bond strength between matrix and fibers did not appear evidently yet, thus lowering the compressive strength of fiber-reinforced concrete.

In case of amorphous steel fiber-reinforced concrete, the

Table 5. Concrete properties on the second day of concrete age

Mixtures	Compressive strength (MPa)	Tensile strength (MPa)	Elastic modulus (MPa)	Instantaneous elastic strain (με)
T-Plain	3.19	0.45	10428	586
T-ASF02	2.04	0.34	8984.2	680

Table 6. Concrete properties on the seventh day of concrete age

Mixtures	Compressive strength (MPa)	Elastic modulus (MPa)	Instantaneous elastic strain (με)
C-Plain	15.07	17497.4	77.2
C-ASF02	12.74	16544.7	81.6
C-ASF03	12.82	16579.3	81.4

mechanism of concrete subjected to ultimate compressive stress is different, or on the other hand, the research is very limited. Thus, further studies are needed to completely understand this behavior. However, in this study, the tests only focused on creep behavior of ASF concrete. Therefore, the compressive strength of concrete was not investigated comprehensively.

3.2 Total creep

Under monotonically sustained loading, creep stress would be reached. The total concrete strain $\varepsilon_{\text{total}}(t,t_0)$ in a uniaxially loaded specimen consists of a number of components:

$$\varepsilon_{\text{total}}(t,t_0)=\varepsilon_{el}(t_0)+\varepsilon_{\text{as}}(t)+\varepsilon_{bc}(t,t_0) \tag{1}$$

where: ε_{el}= instantaneous elastic strain at loading
ε_{as}= autogenous shrinkage
ε_{bs}= basic creep
and t = age of concrete, t_0 = age at loading

3.3 Compressive creep

Fig. 3 shows the compressive creep strain for plain and fiber-reinforced concrete. From the test results obtained, it can be seen that the presence of fibers could significantly change the compressive creep behavior of concrete. In the case of the specimen with a fiber volume fraction of 0.2% (C-ASF02), the reduction was considerably lower than that of the plain specimen (C-Plain), while the specimen with a fiber volume fraction of 0.3% (C-ASF03) was greater than that of C-Plain. However, since the 35th day of concrete age, the compressive creep strain of C-ASF03 has a tendency to decrease and results in the lowest strain. On the 64th day of concrete age, the strain of plain, C-ASF02, and C-ASF03 was 842, 640, and 564με, respectively. Obviously, for a fiber volume fraction of 0.2%, the reduction was approximately 24% while the addition of a fiber volume fraction of 0.3% gave a reduction of 33%.

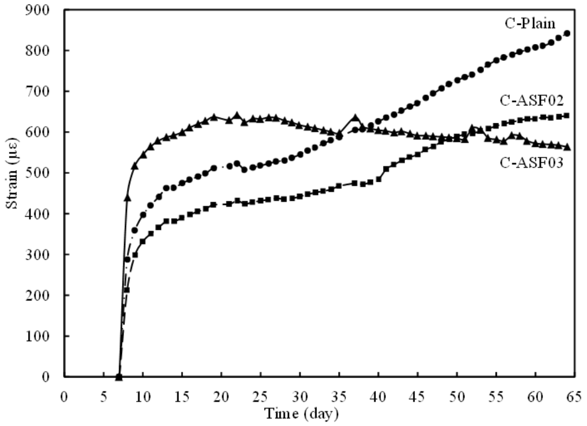


Fig. 3. Compressive creep strain profile

3.4 Tensile creep

Fig. 4 shows the tensile creep strain for the plain and fiber-reinforced concrete. As mentioned in the compressive creep section above, the presence of fibers could significantly change the tensile creep behavior of concrete. However, the effect of fibers was not as obvious as expected. The addition of a fiber volume fraction of 0.2% (T-ASF02) showed much lower strain than that of plain concrete (T-Plain), whereas T-ASF04 showed greater strain than that of T-Plain.

The lowering of tensile creep strain when adding the fiber volume fraction of 0.2% in concrete can be explained as following manner. As developed in Eq. (1), the total creep strain was summarized of an autogenous shrinkage strain and a basic creep strain. In case of tensile creep, the autogenous shrinkage strains would be the opposite direction than the basic tensile creep strains, thus those would affect the curves obtained from the experimental curves. Based on that superposition of strains, once the autogenous shrinkage strain overcomes the tensile basic creep strain, the total tensile

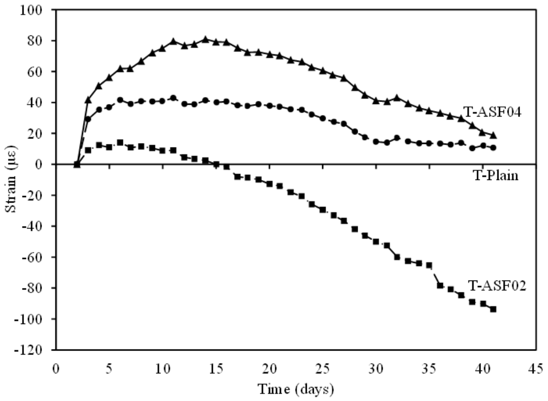


Fig. 4. Tensile creep strain profile

creep strain of concrete will tend to be minus. Obviously, for sealed specimens, the tensile creep is associated with deformation of hydration products such as basic creep and autogenous shrinkage.

In case of T-ASF04, the addition of a fiber volume fraction of 0.4% in concrete resulted in increasing the tensile creep strain. This tendency was verified in the experiment by Bissonnette et al. (1995), Altoubat et al. (2001b), and Mouton (2012), where the use of fibers showed an increase in tensile creep strain. Actually, fibers tend to reduce the initial rate of basic creep, but increase the creep at later stages. That means that relaxation by creep mechanisms in fiber-reinforced concrete continues for a longer time than in plain concrete. This is mainly due to the fibers that have ability to arrest micro-cracks and to engage a larger volume of the matrix in stress transfer. This leads to a lower and more uniform internal stress intensity affecting the creep rate and thus increase the total tensile basic creep. In addition, Saje et al. (2012) investigated that fibers could reduce significantly the autogenous shrinkage by fiber volume fraction. Therefore, total tensile creep of fiber-reinforced concrete in association with basic creep and autogenous shrinkage will increase greater than that of plain concrete. However, the difference in performances of T-ASF02 and T-ASF04 compared with plain specimen (T-Plain) showed that further research is necessary to more fully understand this behavior.

4. Conclusions

Two types of creep tests were carried out to investigate the tensile and compressive creep behavior of amorphous steel fiber-reinforced concrete. From the test results, the addition of fibers could significantly change the creep behavior. For all cases of concrete, tensile creep was lower than compressive creep.

In concern with compressive creep, the presence of a fiber volume fraction of 0.2% in concrete evidently reduces compressive creep. That was due to the presence of fibers in concrete matrix induced restraints. By the restraints of fibers, the matrix creep deformation was considerably compensated (Zhang (2003)). Therefore, the addition of fibers could reduce the compressive creep. However, in case of C-ASF03, the effect of fibers was not evident. Thus, more studies are needed to completely understand this behavior. In tensile creep, the effect of fibers was not evident in comparison with plain concrete. While specimens with a fiber volume fraction of 0.2% showed a decrease in creep strain, on the contrary, specimens with a fiber volume fraction of 0.4% showed an increase. Therefore, further investigations are needed to more fully understand this behavior.

ACKNOWLEDGMENT

This research was financially supported by POSCO Steel Company, and the financial support is gratefully acknowledged. The authors would like to thank Soongsil University for providing a well-resourced laboratory with the necessary equipment to fully complete this project.

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