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UNIAXIAL TENSILE TEST OF UNNOTCHED SPECIMENS UNDER CORRECTING FLEXURE

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Abstract
A uniaxial tensile test is the most objective method for obtaining the tension softening diagrams of concrete. However, it is very difficult to maintain uniform stress conditions in the cross section of specimens because of a secondary flexure. The flexure is supposed to be produced by the initiation of softening not in the whole cross section but from the weakest surface. It is clear that some means are necessary to prevent it in the test. In this paper, some uniaxial tensile tests of unnotched concrete specimens using originally designed apparatus are introduced. A useful bit of information obtained from the tests is also reported.

Key words: Uniaxial tension, test method, tension softening diagram

1 Introduction

Tension softening diagrams of concrete are required to know and analyze fracture behavior of concrete, and to improve the properties of concrete. To obtain the diagrams, bending tests and compact tensile tests have usually been executed. However, the uniaxial tensile test is the most objective method for the purpose and reflects tensile behavior better than any other test.

In order to execute a uniaxial tensile test, a closed loop loading machine is needed. In addition, there are two difficulties to be overcome in the procedure of the test. One is to break specimens in the strain gauge lengths in order to realize a stable fracture. Some investigators used notched specimens for the purpose. However, notched specimens have strong stress concentration, so the exact tensile strength cannot be estimated. The other difficulty is to avoid the secondary flexure and to maintain uniform tensile stress condition in the cross section of the specimens. The flexure is supposed to be produced by the initiation of softening not in the whole cross section but from the weakest surface. Heilmann et al. were the first to adopt three actuators to correct the secondary flexure. However, their measuring length of LVDT used to load control was too large so that they were not able to correct the flexure. Carpinteri et al. were the first to realize the desired condition also using three closed loop actuators. However, their flared specimens also produce stress concentration. The flared specimens restrict the breaking section near the neck without allowing the fracture to occur in the weakest cross section of concrete.

The authors adopted dog-bone and prism specimens without notches or flare. Two originally designed apparatus are tried in their tests to maintain a uniform tensile stress condition in the specimens. Three series of test methods are introduced in this paper along with their results. Some useful information obtained from those tests are also reported.

2 Specimens

Ordinary Portland cement and a maximum aggregate size of 20 mm were used for the concrete specimens. Other information is shown in Table 1. In series 3, high strength and high performance concrete is used.

Table 1 Information of used concrete

Series	1	2	3
W/C (%)	50	60	33
σ_c (MPa)	33.4	29.7	78.0

The unnotched dog-bone specimen and positions of strain gauges in series 1 are shown in Fig.1. The specimen has a uniform cross section of

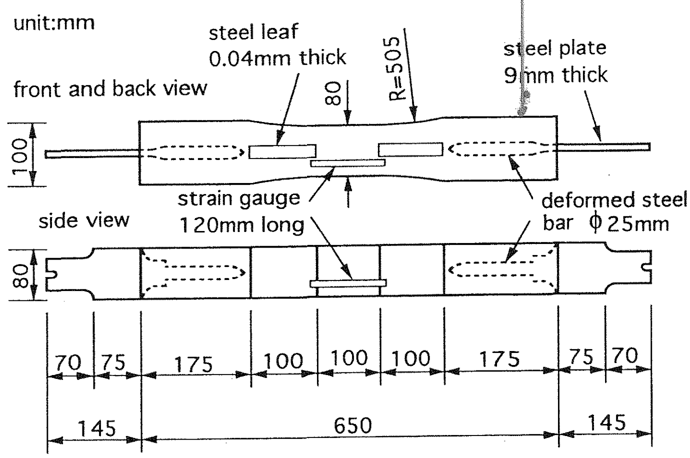

Fig. 1 Dog-bone specimen

80×80 mm and 100 mm in the middle. The relatively small size of the specimen was mainly owed to the size of the loading machine. The large radius of curved haunch was designed to reduce stress concentration. In order to reduce the rigidity descendent between the specimen and the grip of the loading machine, embedded bolts were directly welded to grip end plates. Strain gauges of 120 mm length are glued to 4 faces at 20 mm right side from the centerline of the specimen. The maximum gauge length which enables the control of tensile fracture is known to be not so different from characteristic length for ordinary concrete. As the characteristic length of ordinary concrete is more than 400 mm, the gauge length adopted was small enough to control the fracture process. Steel leaves of 0.04 mm thickness were glued in order to compensate the slight reinforcement produced by the glued strain gauges.

From the results of series 1 test shown later, it is recognized that the loading machine can sufficiently control the fracture process. So, universal joints were adopted in series 2. End gluing instead of bolt embedding allows more simple shape of specimens, i.e. prism specimens. The unnotched prism specimen of 100×100×400 mm and positions of strain gauges in series 2 are shown in Fig.2. The gauge numbers of the upper part are 1 to 4, of the central part are 5 to 8 and of the lower part are 9 to 12. Both ends of the specimen are glued by epoxy resin to the attachments connected to universal joints by pins.

In series 3, both prism and dog-bone specimens were used. Prism specimens are the same as in series 2. The dimensions of the dog-bone specimens are revised a little from those in series 1 as shown in Fig. 3. The revised specimen has a uniform cross section of 100×100 mm and 120 mm in the middle. In this series, the ends of the specimens were glued and tightened by nuts of embedded bolts as shown in Fig.4. As

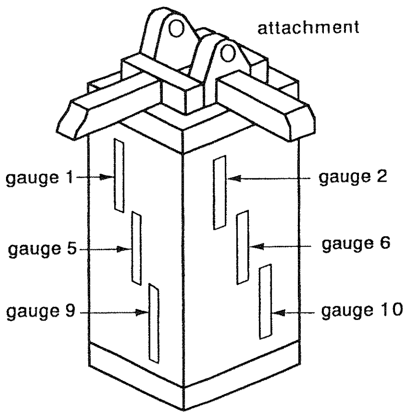

Fig. 2 Prism specimen

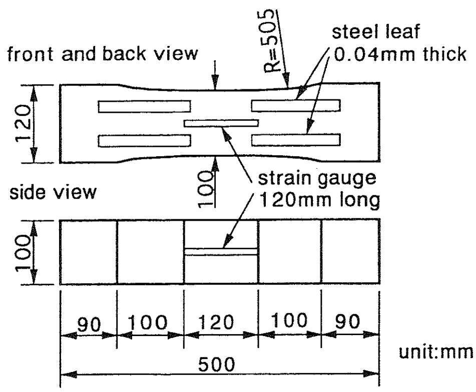

Fig. 3 Revised dog-bone specimen

high strength concrete was used in this series, tensile strength of the specimens was expected to be higher than that of the previous tests. Some reinforcements were necessary, because the tensile strength of glued ends estimated from other test results was near 2 MPa and was not sufficient. This is the reason to adopt embedded bolts in addition to gluing. In addition, strain gauges of 70 mm length were adopted, because the expected gauge length for control of the fracture was less than the previous tests.

3 Test Methods

In order to avoid unstable fracture of specimens, applying load should be controlled by the maximum strain in all strain gauges. It was realized by a channel selector which electrically selected the maximum strain and

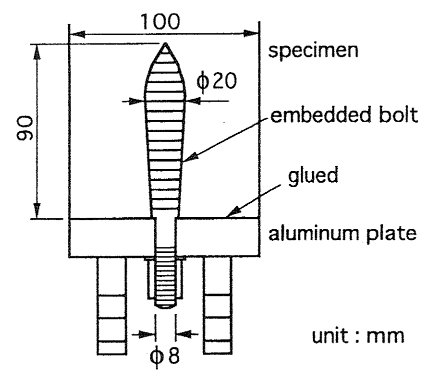

Fig. 4 Embedded bolt

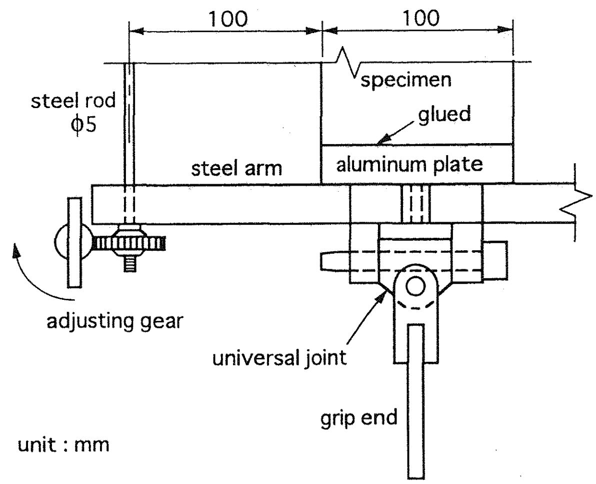

Fig. 5 Apparatus for correcting flexure

sent the signal to the loading machine. The strain rate adopted was 0.02×10^{-6}/sec, because a smaller rate is better for obtaining stable fracture.

In order to correct the secondary flexure caused by the development of a fracture process zone from one side, lateral forces are adopted in series 1. These forces are applied by hand to one or two faces of the specimens by screwing bolts in the centroid. This is the reason why strain gauges were glued on to the right side of the center line.

In series 2, two universal joints were connected to both ends of a specimen in order to eliminate bending produced by a relative inclination of both glued faces. Originally designed apparatus shown in Fig. 5 was adopted for two objectives. One is to correct the secondary flexure, the other is to eliminate the bending produced by eccentricity of both the universal joints pins from the central axis of the specimen. By screwing the handle connected to the adjusting gear, a strain of 10^{-6} in the surface of the specimen is easily adjusted. As the rods are 400 mm lengths and 100 mm apart from the specimen's faces, 0.0012 mm are a necessary contraction to be adjusted. Because the pitches of screw threads are 0.5 mm and the horizontal gear has 50 threads, 10% of one rotation by the vertical gear is sufficient and easily adjustable. If universal joint pins have 1 mm eccentricity from the central axis of the specimen, 1/150 of the applied load is a necessary force to eliminate the bending from the eccentricity.

In series 3, the test method is almost the same as in series 2.

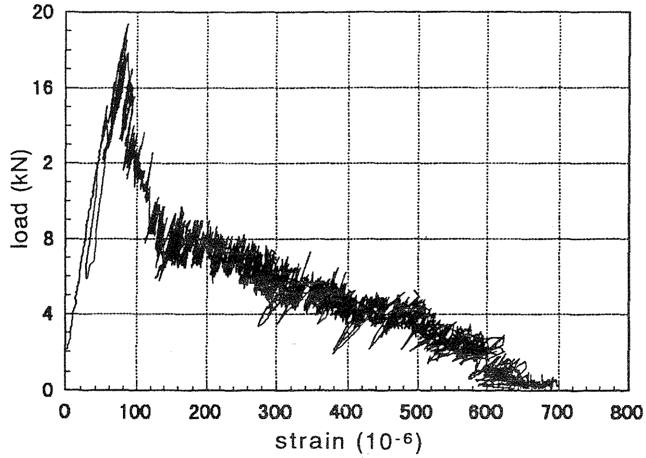

Fig. 6 Load-strain diagram of series 1

4 Results and discussions

Figure 6 is a load-strain diagram obtained from the series 1 test. The up and down of the applied load results from the adjustment of opposite face strain in order to become equal to each other. When opposite face strains are adjusted to be equal to each other, the machine increases the applying load. If it is left as it is, the difference of the opposite face strains increases gradually, because uniformly distributed stress conditions are unstable in load descending branch. In fact, more than 40

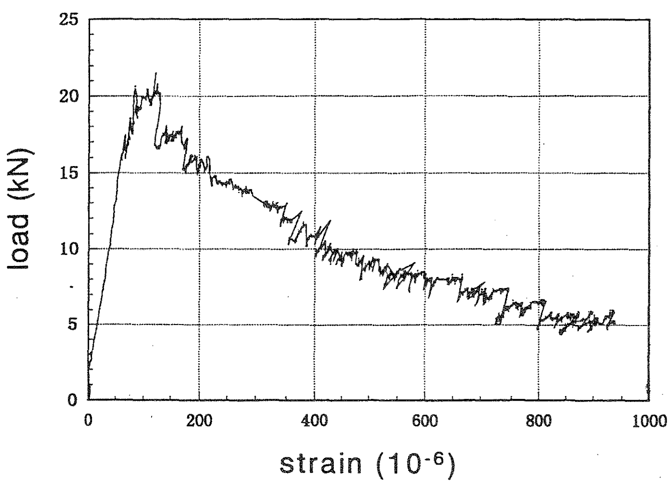

Fig. 7 Load-strain diagram of series 2

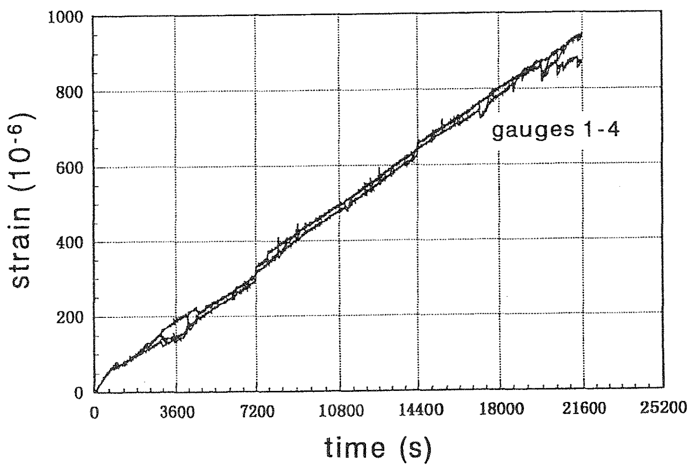

Fig. 8 Strain-time diagram

minutes were spent during the first descending slope. In addition, many oscillations of applied load are observed in the duration in Fig. 6. These results show that the loading machine can sufficiently control the tensile fracture process.

The similar diagrams were obtained from 2 out of all 7 specimens. All other specimens were suddenly broken outside of strain gauges and their post peak fracture could not be controlled. Referring to the above small success ratio, it is concluded that the test method should be improved.

Figure 7 is also a load-strain diagram obtained from the series 2 test. The descending branch after peak is not so steep as Fig. 6. One of the possible reasons is the drying of the specimen for two days before the test. The drying produces tensile stress and shrinkage cracks near the surface of the specimen. They cause gradual softening from the surface rather than the uniform softening throughout the cross section. This can be seen in the strain-time diagrams of the same specimen. Figure 8 shows the diagram of the softening cross section belonging to strain gauges 1 - 4. Four strains increase linearly and are nearly equal to each other. This is because machine load was controlled by one of these strains, and opposite face strains were adjusted to become equal to each other. Figure 9 shows strain-time and load-time diagrams in another cross section of the same specimen belonging to strain gauges 9 - 12. After peak load, all 4 strains decrease and become zero at 10,800 secs. However, the applied load is still 9 kN at that time. This means that stress does not exist near the surface but in the inner part. As shown in Fig. 10, this also suggests that softening is more developed near the surface than the inner part and that it develops gradually from the surface.

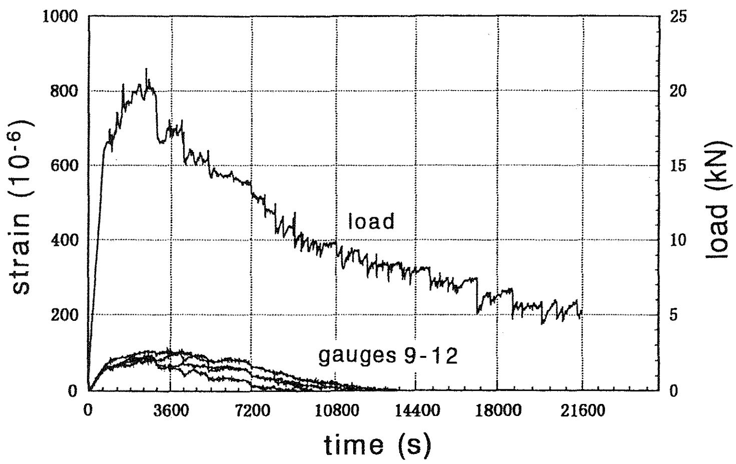

Fig. 9 Strain-time and load-time diagrams

Similar diagrams were obtained from 4 out of all 7 specimens. However, the peak load was not always exact, because strain adjustment was not always complete in the softening cross section. The reason for incompleteness comes from the difficulty in finding the cross section to be adjusted. In fact, fairly large strains appear in two or three gauges, e.g. in gauges 1, 7 and 9 or in gauges 1, 7 and 11 etc. If gauge 7 has the largest strain and is adjusted so as to down in gauge 7 and raise in gauge 5, the opposite face strains such as in gauge 1 or 9 will exceed that in gauge 7. These situations prevent us from selecting the cross section to be adjusted. It is concluded from the series 2 test that to find the cross section to be adjusted should be the next subject.

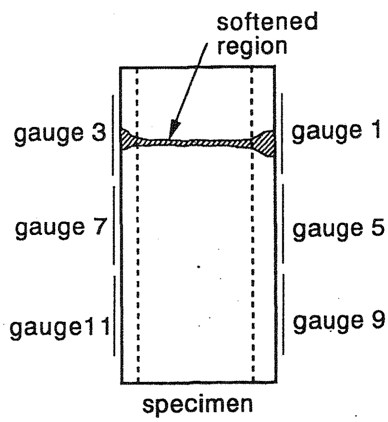

Fig. 10 Softened region

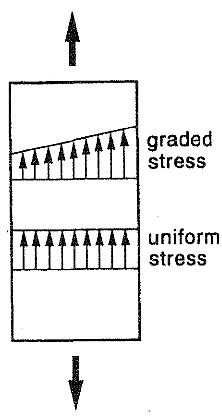

Fig. 11 Stress distributions

From the following consideration, it is concluded that tension softening will always occur in different cross sections from those being adjusted. As illustrated in Fig. 11, the maximum stress is always larger in a graded cross section than a uniformly distributed cross section because resultant force is equal to the applied load in every cross section. Taking this into consideration, it is assumed that larger strain correlates to larger stress even if the relationship is not linear.

In series 3 test, steel leaves 95 mm wide were glued to 4 side faces in the upper and lower parts of the specimens in order to prevent initiation of softening there. However, the embedded bolts yielded near the nuts before tension softening occured in the concrete for all specimens. The main reason is too large a tensile strength compared with the diameter of the embedded bolt screw ϕ8 mm.

The test of series 3 failed. However, the direction of improvement for a next test is clear. The authors are making a plan to execute the next test using embedded bolts of a larger diameter.

5 Conclusions

A uniaxial tensile test of concrete specimens without notch and flare seems to be a possible method. The most important factor remaining is to find a lower level of reinforcement on the upper and lower parts of the 4 faces in order to prevent the initiation of softening there.

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