CHARACTERISTICS OF FRACTURE PROCESS ZONE OF CONCRETE EVALUATED WITH 3-D ACOUSTIC EMISSION TECHNIQUE

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Tension softening behavior of concrete is highly dominated by the existence of fracture process zone ahead of the crack tip. It is hardly possible, however, to directly observe the fracture process zone.

In this paper, three dimensional acoustic emission technique (3-D AE) is applied to observe the phase of the fracture process zone of concrete. The results show that the fracture process zone is widely created at the peak load and then the zone with active AE events moves towards the bottom of the specimen.

INTRODUCTION

Tension softening behaviour of concrete is highly dominated by the existence of fracture process zone ahead the crack tip. Unfortunately it is hardly possible to directly observe the fracture process zone and several indirect observation techniques have been applied (1). Most of them, however, are available to observe only the surface of specimens but the fracture process zone has a three dimensional structure.

In this paper, three dimensional acoustic emission technique is applied to observe the phase of the fracture process zone of concrete. The results show some aspects of the fracture process zone changing with the crack extension.

3-D AE MONITORING SYSTEM FOR SOURCE LOCATION ANALYSIS

The acoustic emission (AE) monitoring system equipped with 8 channels of AE transducers are used. The resonant frequency of the transducer used in this test is 140kHz. The transducer is inserted

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into a metallic tube which is fixed on the specimen surface with adhesive. The signals from the transducer are amplified by a pre-amplifier and a discriminator. Output signals are directly digitalized by a transient recorder with 50ns sampling interval. The number of the samples is 1000 per one channel. Totally 8000 digitalized AE data per an AE event are transferred over GPIB and stored in a hard-disk of a personal computer. Since it takes about 1.2 seconds to transfer and store all data via the GPIB, AE signals generated during the data transferring may be lost. After testing a specimen, all digitalized AE waves are stored in a laser-disk.

AE source location calculation is carried out by a soft-ware developed by Niiseki and his co-workers (2). The relative times of arrival are automatically evaluated and the AE source location is calculated by an algorithm based on an iteration method. The mean value of the erroneous of the source location calculation for the used concrete was 3.4mm.

EXPERIMENTAL PROCEDURES

Double cantilever beam (DCB) specimens were tested, whose height, width and thickness were 600, 440 and 120mm, respectively. There was a triangle groove of 10mm depth on the both sides of the specimen. It means the actual ligament thickness was 100mm. There were three test series (C1, C2 and C3) whose notch lengths were changed with 300mm, 350mm and 400mm, respectively. In each series, three specimens were tested.

Mix proportion of concrete are given in TABLE 1. Ordinary Portland cement, river sand and crushed stone from Miyagi Prefecture were used. The water to binder ratio was 0.40 and the maximum aggregate size was 25 mm. All DCB-specimens were cast with their largest side being horizontal. The notch was cast using a 2.1mm thick greased steel plate. After demoulding, they were lapped with wet cloths and vinylon sheet to get a humid condition and stored in a testing room until the test age of 28 days. The mean values of compressive strength, tensile strength and Young's modulus of cylinders cured in the same condition as that for the test specimens, were 50.9MPa, 3.94MPa and 3.19×10^4MPa, respectively.

TABLE 1. Mix Proportion of Concrete. (kg/m^3)

d_{max} (mm)	W/C %	W/(C+Si) %	W	C	Sand	Gravel	Silica-fume	Superpl. (cc/CW)	Comp. Str. (Mpa)
25	47	40	160	340	721	1006	60	12.1	50.9

A servo-controlled hydraulic jack was used to give the DCB specimen a cyclic load. Besides the load, both the crack mouth opening displacement and the crack opening displacement at the notch tip were measured and recorded for all specimens. Acoustic emission signals were also monitored by means of eight transducers. Every four transducers were arranged at the corners of a rectangle on both side of the specimen as they surrounded the crack tip. After the crack grown up to a certain distance, their position was moved after unloading in order to keep the accuracy of the source location calculation on the almost same level. The test set-up is shown in Figure 1.

EXPERIMENTAL RESULTS AND DISCUSSION

An example of the results of AE source location calculation is shown in Figure 2. The phase of the fracture process zone can be clearly observed from the source location map. This figure shows that a fracture process zone has been widely created ahead the notch tip at the peak load and then the zone with active AE events moves towards the bottom of the specimen. The difference of notch length introduced in these tests did not give any obvious influences on the observed AE properties.

It may be worthwhile to notice that the AE event distribution up to the peak load is almost constant in the direction vertical to the notch line (Figure 3), but that the distribution along the notch line is clearly changed (Figure 4). At the peak load, the length of the fracture process zone has been already reached to about 70 mm which is nearly three times as long as the maximum aggregate size.

Figure 5 shows that the AE event distribution in the direction vertical to the notch line up to the peak load is almost same or only a little different from that after the peak load. It may mean that the width of the fracture process zone is almost constant or even slightly decreases with the crack growth in case of high strength concrete such as one tested in this study. This tendency may be changed in normal concrete (3). The widest distance from the notch line was about 70mm.

CONCLUSIONS

Three dimensional AE technique is very useful to study the behaviour of the fracture process zone of concrete. The phase of the fracture process zone can be clearly observed from the AE source location maps. The AE event distribution up to the peak load is almost constant vertical to the notch line, but the distribution in the direction along the notch line is clearly changed.

A fracture process zone was widely created ahead the notch tip at the peak load. The length of the fracture process zone was nearly three times as long as the maximum aggregate size. The width of the fracture process zone is not changed or even slightly decreases with the crack growth in case of high strength concrete.

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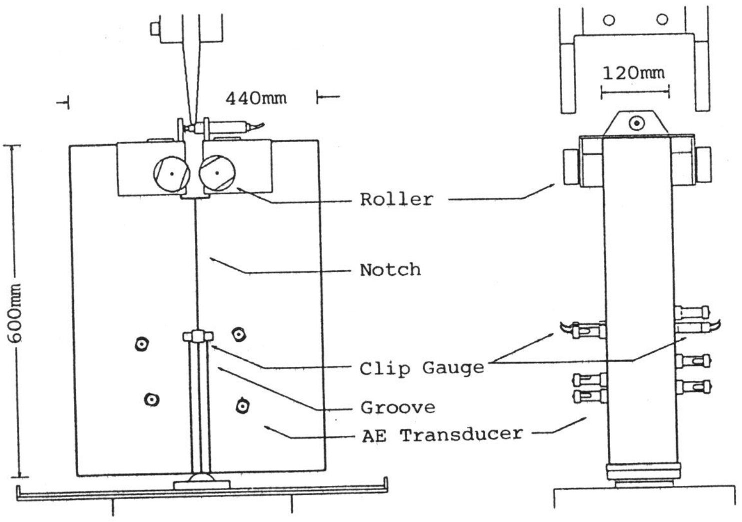

Figure 1 Test set-up

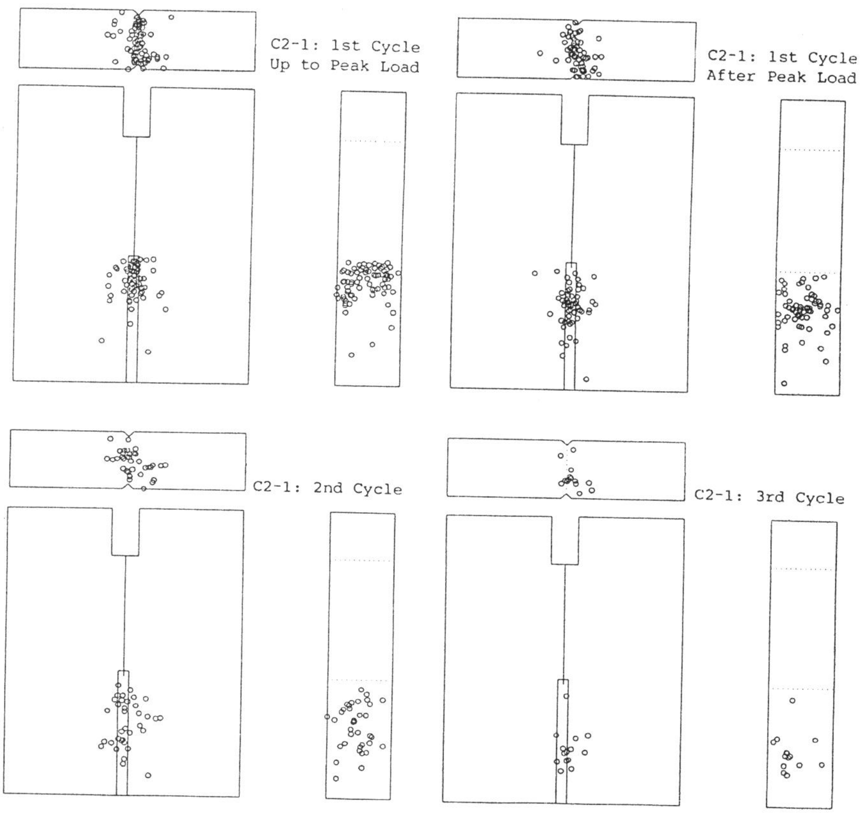

Figure 2 Example of AE source location map

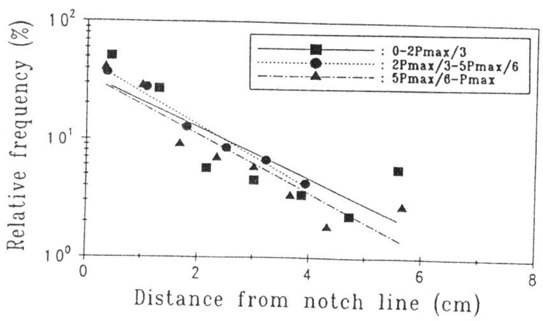

Figure 3 AE event distribution in the direction vertical to the notch line up to P_{max}

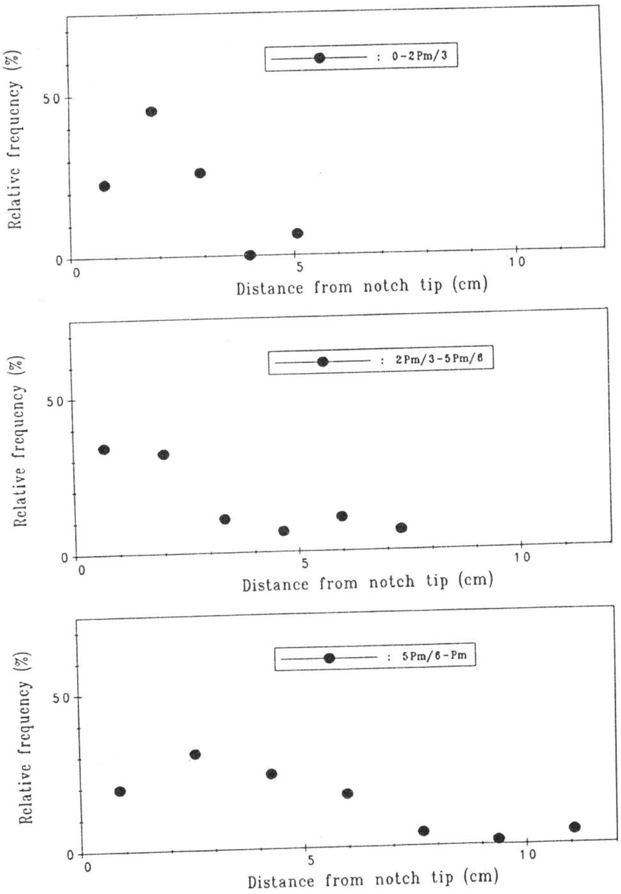

Figure 4
AE event distribution along the notch line up to P_{max}: (C1 Series)

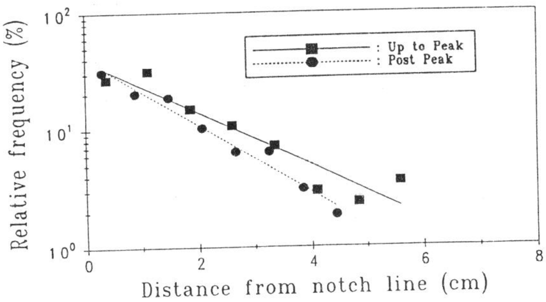

Figure 5 Changing properties of AE event distribution in the direction vertical to the notch line up to and post P_{max}