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The effect of gamma radiation on the fracture properties of concrete

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ABSTRACT: Concrete structures for nuclear power plant or radiation medical facilities may be subjected to the gamma radiation conditions for a long period. This paper reports on the investigation into the fracture properties of concrete subjected to the effects of the gamma radiation. Three-point bending tests were conducted to measure the load versus crack mouth opening displacement (L-CMOD) curves. The initial cohesive stress and fracture energy were estimated by the inverse analysis of tension softening diagram calculated by the L-CMOD curve. The effect of the gamma radiation on the fracture properties was discussed.

1 INTRODUCTION

Concrete structures for nuclear power plant or radiation medical facilities may be subjected to the gamma radiation action for a long period. Many studies have already reported that the strength of concrete subjected to the gamma radiation can be retained by maintaining the conditions of not more than 2.0×10^{10} rad under general control standards for nuclear power plant. The effect of the gamma radiation should be considered to discuss the long-term safety and the durability of concrete structures. However, the fracture properties of concrete under the gamma radiation are not yet clarified.

On the other hand, evaluation of the fracture parameter for inelastic materials is an important subject in the field of fracture mechanics of concrete. It has been pointed out by many researchers that the tension softening diagram (TSD) is a very useful basic parameter characterizing the fracture behavior of concrete. TSD can also be used to estimate the crack starting strength and the crack resistance in the crack propagation, and it may give us a lot of information on the elastic-plastic fracture parameter. The poly-linear tension softening inverse analysis was proposed by Kitsutaka et al. (1994, 1997) and this method was authorized for Japan Concrete Institute Standard (JCI-S-001-2003) as an appendix method of estimating tension softening curve of concrete.

In this study, the fracture properties of concrete subjected to the effects of the gamma radiation were investigated.

2 OUTLINE OF EXPERIMENT

2.1 *Test conditions*

Tables 1 and Table 2 give the materials and designed mixture proportions respectively. Water-cement ratios (W/C) was 0.5. Maximum aggregate size (Gmax) was 10 mm. Specimen size was 40 x 40 x 160 mm.

Table 3 gives the test factors and levels. The accelerated gamma radiation tests were conducted at the Takasaki Advanced Radiation Research Institute of Japan Atomic Energy Agency. After the 4-week water curing at 20°C and 6-week air curing at 20°C and 60%RH, specimens were set in the gamma radiation conditions for 1 and 2 months. In case of 2 months, additional far position specimen was set. The total amount value of gamma radiation was 7.2×10^8, 13.0×10^8 and 4.6×10^8 rad respectively. The temperature and humidity conditions were about 17°C and 50%RH. Also blank specimens were cured under 20°C and 60%RH for 1 and 2 months.

After the gamma radiation, three-point bending tests for notched specimen were conducted to measure the load versus crack mouth opening displacement (L-CMOD) curves. Test conditions follow the JCI Standard (JCI-S-001-2003). A servo-controlled hydraulic tester having a closed loop system (manufactured by MTS) was used. Specimen was loaded with constant CMOD speed. Sensitive clip gauges for displacement control (MTS-632.02) were used for the CMOD measurement. Test set up is shown in Figure 1.

The tension softening diagram (TSD) was determined by poly-linear approximation analysis method (Kitsutaka et al. 1994) based on the obtained load-CMOD curves. This analysis method is authorized in the JCI Standard (JCI-S-001-2003) as an Appendix. Fracture parameters, such as fracture energy and the initial cohesive stress were evaluated from the obtained tension softening diagram. After the bending tests, compressive strength was measured for the braked cubic specimen.

Table 1. Materials used for the experiment.

Materials	Mark	Detail
Cement	C	Ordinary portland cement, Specific gravity=3.16g/cm^3
Fine aggregate	S1	Pit sand, Specific gravity=2.50 g/cm^3 Absorption=2.45%, F.M.=2.12
Fine aggregate	S2	Crushed sand, Specific gravity =2.64g/cm^3, Absorption=1.23% F.M=3.01
Coarse aggregate	G	Crushed stone, Specific gravity =2.66g/cm^3, Absorption=0.97% Abso lute volume=59.5%, Gmax=10mm
Admixture	Ad	Air entraining and water reducing agent

Table 2. Designed mixture proportions of concrete.

W/C %	Gmaxmm	Air %	S/a %	W kg/m^3	C kg/m^3	S1 kg/m^3	S2 kg/m^3	G kg/m^3	Ad C%
50	10	4.5	45	180	360	223	550	967	0.25

Table 3. Factors and levels.

Symbol	Total period (month)	Specimen position	Gamma radiation level (kGy/h)	Gamma radiation period (month)	Total amount of gamma radiation value (Rad)
gn0m	0	-	0	0	0
gn1m	1	-	0	0	0
gn2m	2	-	0	0	0
gh1m	1	Near	11.3	1	7.2 x 10^8
gh2m	2	Near	11.3	2	13.0 x 10^8
gm2m	2	Far	3.9	2	4.6 x 10^8

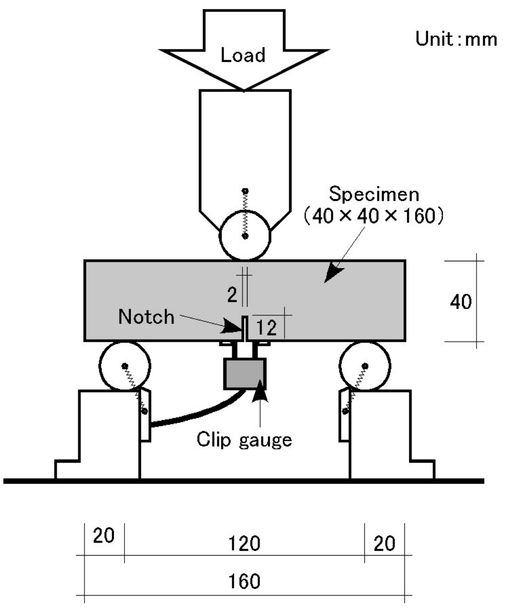

Figure 1. Three-point bending test for center notched specimen.

2.2 *Poly-linear inverse analysis method of tension softening diagram*

The author has demonstrated the basic concept of analyzing the poly-linear TSD from a measured load displacement curve. The softening inclination m_k and COD of node 1 at step k (δ_{k1}) were determined by optimizing the load calculated by a crack equation analysis to the load obtained by an experiment. In this step, former values of all m_k and δ_{k1}were fixed and they were used as the constitutive law for calculation. This method can be summarized by stating that the relationship between COD and cohesive stress on node 1 (the fixed point $x=a_0+0.5l_1$) is calculated considering the boundary conditions of all nodes for each step. Because of the monotonous increase of COD from a crack tip to a crack mouth, in the case of uniform materials, the COD of node 1 is the largest in every calculation, therefore the constitutive law for all CODs should exist for each step and optimum TSD should be obtained. Young's modulus can be obtained from the initial inclination of load point displacement curve, σ_0 can be determined by analyzing the initial load point displacement curve temporary assuming the softening inclination to have the constant value of zero (Dugdale model).

3 TEST RESULTS AND DISCUSSIONS

3.1 *Compression test*

Figure 2 shows the results of compression tests. The compressive strength of the specimens subjected to the gamma radiation for 1 month and 2 month (gh1m, gh2m, gm2m) tend to the same as those of the no-radiation blank specimens (gn0m, gn1m, gn2m).

3.2 *Load- crack mouth opening displacement curve*

Figure 3 shows typical load-crack mouth opening displacement (L-CMOD) curves of the specimens. Stable load displacement curves were obtained for all tests. The surrounding area of L-CMOD curve of the specimen subjected to the gamma radiation (gh, gm) tends to be lower than those of the specimen without gamma radiation (gn). The surrounding area of L-CMOD curve of the specimen subjected to the gamma radiation for the curing period 2 months (gh2m) tends to be lower than those of the specimen for the curing period 1 month (gh1m).

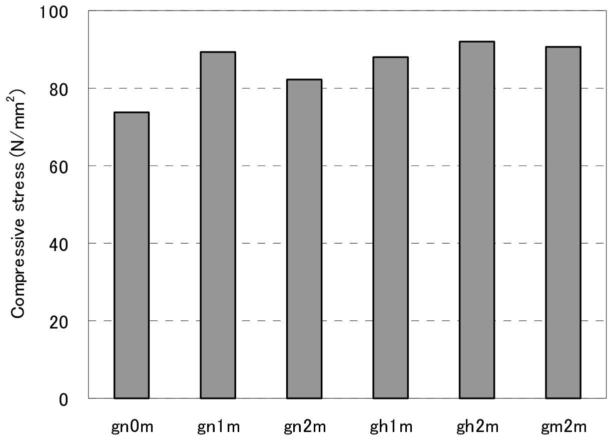

Figure 2. Result of compression tests.

3.3 *Tension softening diagram*

Figure 4 shows the tension softening diagram (TSD) analyzed from observed load-crack mouth opening displacement (L-CMOD) curve of the specimen. The surrounding area of the tension softening diagram (TSD) of the specimen subjected to the gamma radiation for the curing period 2 months tends to be lower than those of the specimen for the curing period 1 month and this is the same tendency of the observed load-crack mouth opening displacement (L-CMOD) curve.

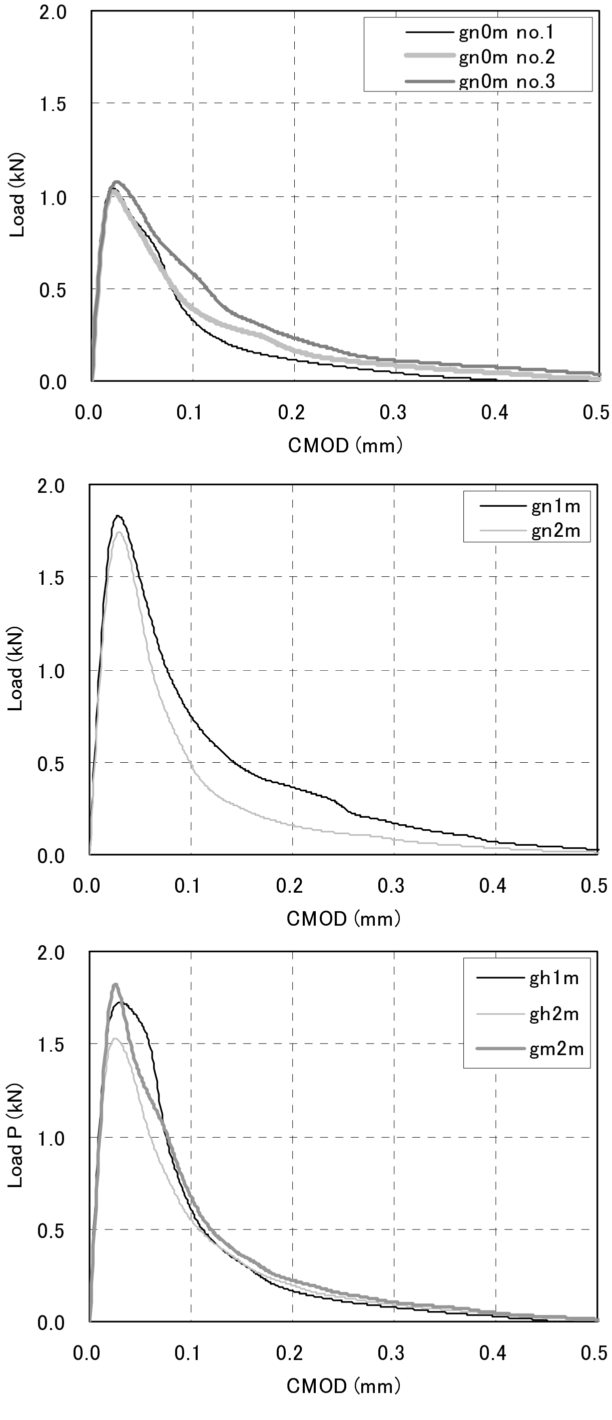

Figure 3. Typical load - crack mouth opening displacement (L-CMOD) curve.

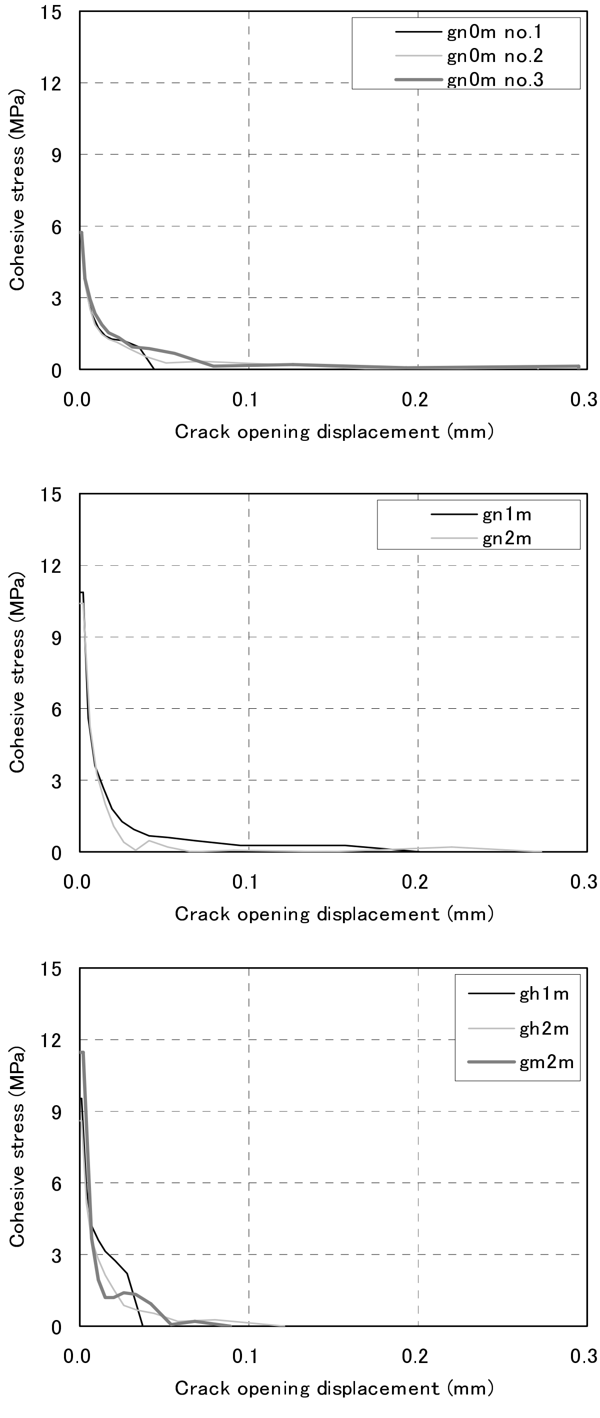

Figure 4. Analyzed tension softening diagram (TSD).

3.4 *Initial cohesive stress*

Figure 5 shows the initial cohesive stress of TSD. Initial cohesive stress indicates the crack starting strength. The initial cohesive stress of the specimen subjected to the gamma radiation tends to be lower than those of the non-radiation blank specimen. Also the initial cohesive stress of the specimen subjected to the gamma radiation for the curing period 2 months(gh2m) tends to be lower than those of the specimen for the curing period 1 month(gh1m) and those of the specimen at far radiation position for the curing period 2 month(gm2m). This is because the gamma radiation causes the increase of the temperature of the specimen and this causes the micro crack of paste matrix and the initial cohesive stress of the specimen becomes low.

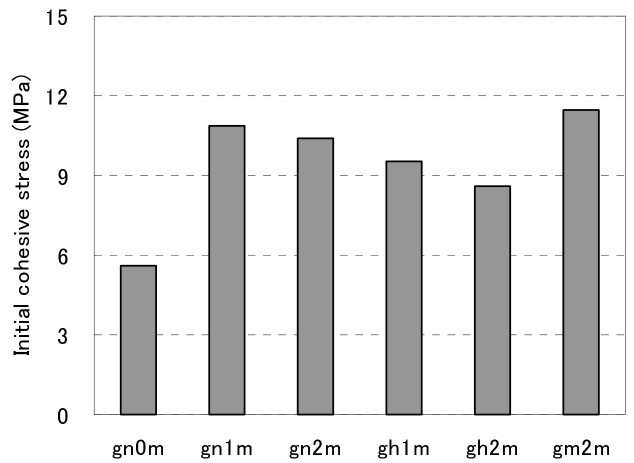

Figure 5. Initial cohesive stress.

3.5 *Fracture energy*

Figure 6 shows fracture energy which was calculated from the surrounded area of TSD. Fracture energy of the specimen subjected to the gamma radiation for the curing period 2 months(gh2m) tends to be lower than those of the specimen for the curing period 1 month(gh1m) and those of the specimen at far radiation position for the curing period 2 month(gm2m).

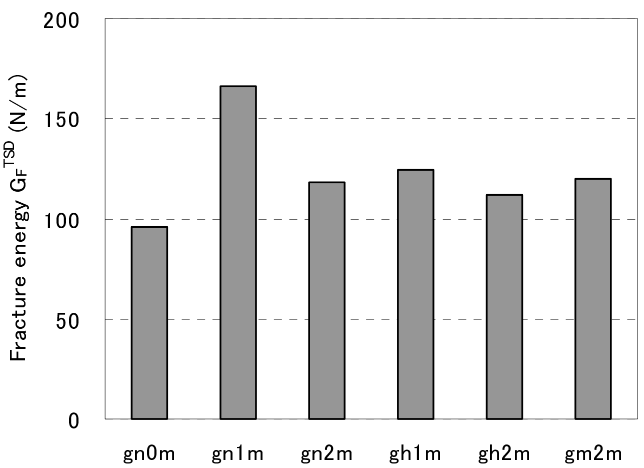

Figure 6. Fracture energy.

4 CONCLUSIONS

This study was performed in order to make clear the effects of the gamma radiation on the fracture properties of concrete. The main conclusions are as follows:

(1) The compressive strength of the specimens subjected to the gamma radiation tend to the same as those of the no-radiation blank.

(2) The initial cohesive stress of the specimen decreases with the increase of the total amount of gamma radiation value.

(3) Fracture energy of the specimen subjected to the gamma radiation tends to be lower than those of the non-radiation blank specimen

(4) The reduction of the fracture toughness of the specimen subjected to the gamma radiation is considered that the micro crack of paste matrix becomes high with the increase of the gamma radiation.

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