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Detection of Thermal Cracks in Early-Age Concrete by AE

T. Watanabe[1c], T. Ohno[2], and C. Hashimoto[1]

[1] *Department of Civil and Environmental Engineering*
The University of Tokushima, JAPAN
[2] *Tekken Corporation, JAPAN*

Abstract

Early-age cracking after casting is a fundamental problem for the durability of concrete structures. Recently, thermal cracks and early-age cracks have been observed in concrete containing Portland cement with blast-furnace slag in Japan. In order to reduce the number of these cracks, fly ash is substituted for cement or sand. Fly ash is one of the popular admixtures as a waste material from coal-fired power plants. To evaluate the effect of fly ash on early-age cracks, experimental studies were performed. In order to detect micro-cracking in concrete, acoustic emission (AE) measurement was applied. In experiments, two types of fly ash, type Ⅱ and Ⅳ categorized by JIS were employed. The ratio to substitute cement and sand was 10% and 20%. As a result, micro-cracks in concrete were detected by the AE method. Results show that substitution of fly ash for cement and sand is effective to reduce micro-cracking due to thermal changes which occurs from 20 to 30 hours elapsed after casting of concrete.

Keywords: Thermal cracks; AE method; Blast-furnace slag; Fly ash, Early-age cracks.

1. Introduction

Early-age cracking after casting is considered to be an essential problem for the durability of concrete structures. In Japan, Portland cement mixed with blast-furnace is widely employed to prevent concrete from thermal cracking by reducing heat of hydration. Recently, however, thermal cracks and early-age cracks have been observed in concrete containing Portland cement with blast-furnace slag. This is because the function to reduce heat of hydration becomes weak in order to improve the early-age strength.

As a remedy to reduce the occurrence of early-age cracks in concrete of Portland cement with blast-furnace slag, fly ash is known to be applicable to substitute for cement and sand. Previously, it was observed that the number of settlement cracks and the averaged crack-widths decreased with the substitution of fly ash for sand [1]. The settlement crack is one example of the early-age cracks. In order to evaluate the effect of fly ash on preventing from early-age cracks, experiments on

[c] Corresponding Author: Takeshi Watanabe
Email: watanabe@ce.tokushima-u.ac.jp Telephone: +81 88-656-7320 Fax: +81 88-656-7351
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thermal cracks are performed. To detect micro-cracking readily, acoustic emission (AE) method is applied in the measurement.

2. Experiments

2.1. Mixture proportion and physical properties of materials Governing equations

Four kinds of concrete mixes; BBFA0, BBFA20, BBFA10, NFA20 are shown in Table 1. Physical properties of materials are given in Table 2. In this study two types of fly ash, type Ⅱ and Ⅳ categorized by JIS are used. BBFA10 is a control concrete without fly ash, using Portland cement with blast-furnace slag. BBFA20 is a concrete using fly ash of type Ⅱ by substituting 20% Portland cement with blast-furnace slag. BBFA10 is concrete using fly ash of type Ⅳ by substituting 10% sand. NFA20 is a concrete using fly ash of type Ⅱ by substituting 20% ordinary Portland cement.

TABLE 1: MIXTURE PROPORTION OF CONCRETE SPECIMENS

Specimens	G_{max} (mm)	Slump (cm)	Air (%)	W/C (%)	s/a (%)	Unit wait (kg/m^3)						
						W	C	FA	S	G	AD	AE
BBFA0	20	10 ± 2.0	4.5 ± 1.5	54	46.5	166	308	-	822	946	3.08	1.54
BBFA20				46	44.5	162	282	71	766	953	3.53	4.59
BBFA10				54	45.5	164	304	68	727	969	3.04	5.32
NFA20				46	44.5	164	286	71	766	953	3.57	3.93

W: water, C: cement, FA: fly ash, S: sand, G: gravel, AD: super plasticizer, AE: air-entrained agent

TABLE 2: PHYSICAL PROPERTIES OF MATERIAL.

Material	Properties
Cement	Portland blast-furnace slag cement, Type B (JIS Category) ρ=3.04g/cm^3
	Ordinal Portland cement, ρ=3.15g/cm^3
Fly ash	Fly ash Ⅱ (JIS Category) ρ=2.28g/cm^3
	Fly ash Ⅳ(JIS Category) ρ=2.20g/cm^3
Sand	Crushed sand, ρ=2.57g/cm^3, F.M. 2.95
	Sea sand, ρ=2.57g/cm^3, F.M. 2.00
Coarse aggregate	Crushed stone (15-5mm), ρ=2.57g/cm^3
Admixture	Super plasticizer (polycarboxylic acid type) and AE

2.2. Detection and Evaluation of Cracks

A sketch of a specimen tested to evaluate thermal cracks is shown in Fig.1, of which dimensions are 1800 mm x 900 mm x 400 mm. A deformed steel bar with 22 mm diameter is set at a height of 50mm from the bottom of the specimen. This bar served as a waveguide of AE detection in addition to reinforcement. Gauges to detect strain and temperature are also set as denoted in the figure. Measurement of AE activity, strain and temperature started right after casting of concrete.

AE phenomenon is defined as elastic-wave emission produced by micro-fracturing in a solid [2]. Time history of AE hits is useful for detection of cracking in concrete. In most cases, abrupt increase of AE hits is associated with failure in concrete. This is because AE activity is physically correlated with nucleation of cracks in concrete.

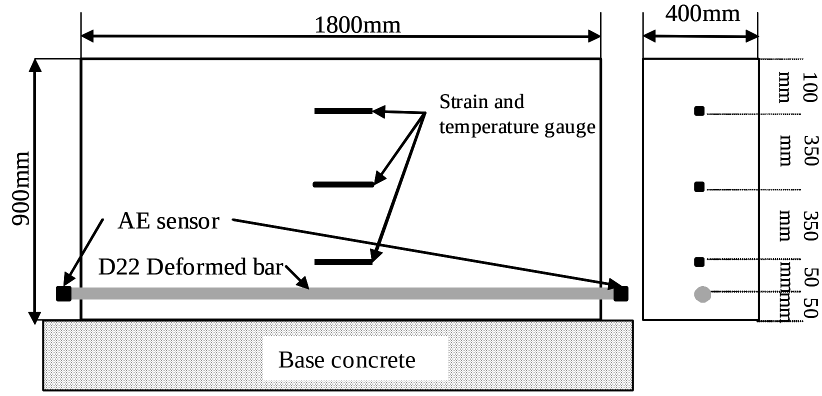

Figure 1. Sketch of specimen for evaluation of thermal cracks.

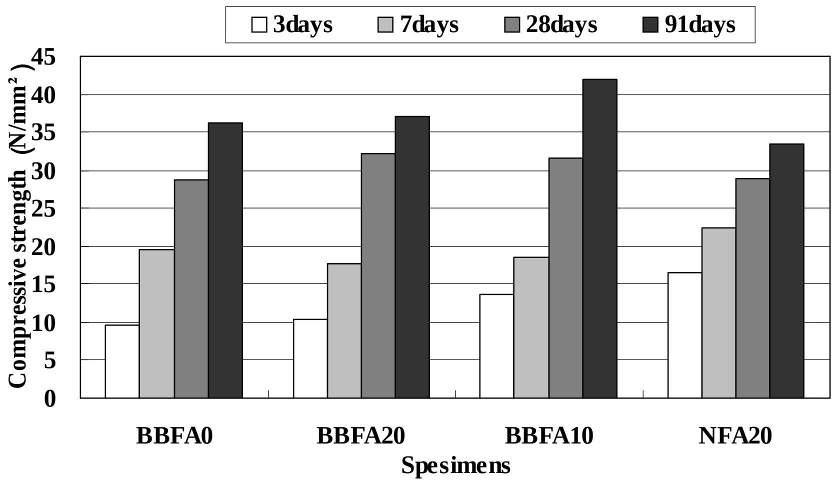

Figure 2. Results of compressive tests.

3. Results and discussion

Results of the compression tests based on JIS A 1108 are shown in Fig. 2. Compressive strengths of all specimens are about 30 N/mm^2 at 28days. This is because mixture proportions in Table 1 are controlled to keep the compressive strengths around 30 N/mm^2.

In order to detect thermal cracks, AE sensors were attached to both ends of rebar in the specimen as shown in Fig. 1. Relationships between cumulative AE hits and temperature in concrete are presented in Fig. 3. Here, AE hits which were detected by both sensors are only plotted. Since AE activity is different in each specimen, evaluation is conducted qualitatively in the relationship with temperature. Concerning temperature variations, reduction of the maximum temperate with addition of fly ash is not clearly observed. Cumulative AE hits of all specimens increase between 20 and 30 hours elapsed. It is considered that concrete temperature increases from 0 to 20 hours elapsed due to hydration of cement, and then temperature decreases. A similar trend is observed in strain changes. In a laboratory test, it was observed that AE hits were actively detected until when temperature started decreasing [3].

Comparing AE activity between BBFA0 and BBFA10, it is found that almost of all AE hits are observed from 20 to 50 hours elapsed in BBFA0. AE hits in BBFA10 also occur from 20 to 50 hours elapsed, although AE activity is fairly low in this period and AE hits are continuously observed until 150 hours. In BBFA20 and NFA20, AE activities have two highly active periods at 20 hours and after 100hours. These results imply that fly ash acts effectively to reduce micro-cracking due to thermal changes in the early stage (the first active period) from 20 to 30 hours after casting concrete. Based on visual inspection, the second active period could be associated with drying shrinkage of concrete.

Results of visual inspection on crack widths are summarized in Table 3. These cracks were not recognized right after casting, but found within a week after casting. This implies that a driving force for these cracks could be not only thermal change but also drying shrinkage. According to experimental observation, it seems that micro-cracks due to thermal change occur fast, and then cracks grow due to drying shrinkage. In Table 3, it is observed that averaged crack widths of specimens are almost similar except NFA20, where cracks are not observed.

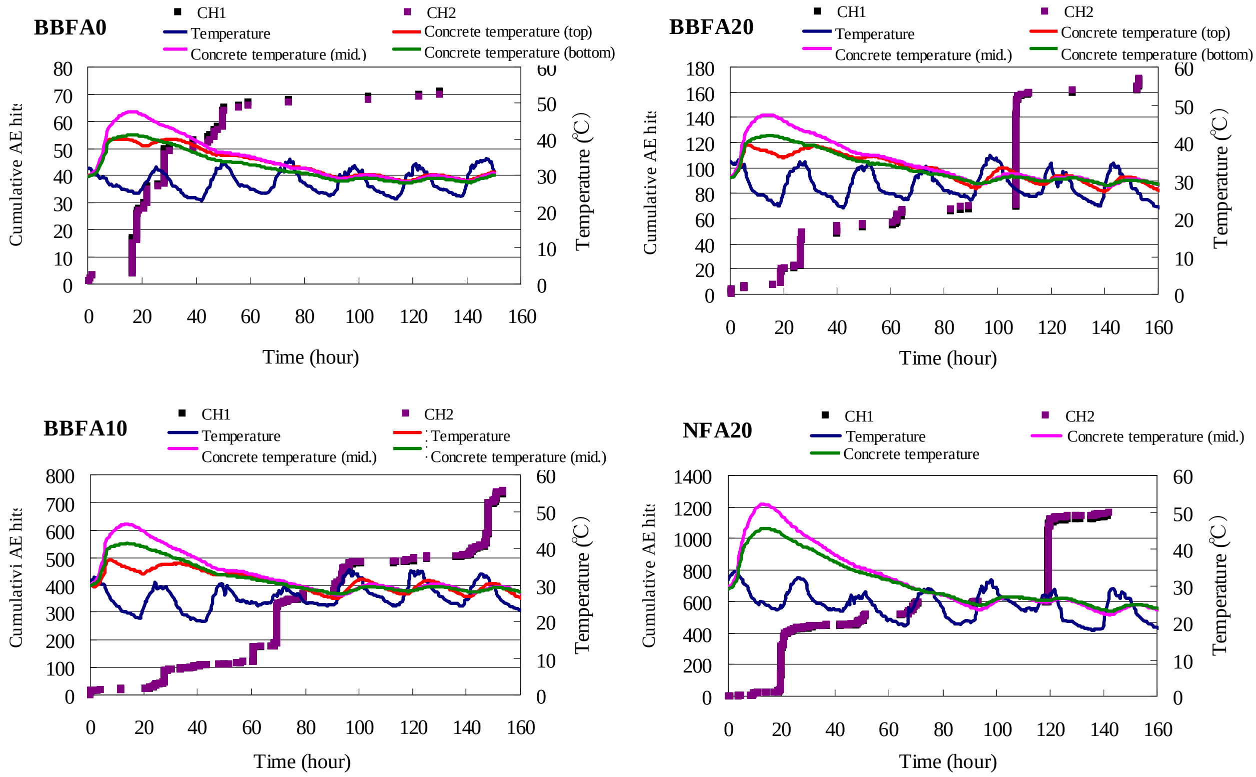

Figure 3. Relationship between cumulative AE hits and temperature in concrete.

TABLE 3: CRACK WIDTHS IN SPECIMENS (mm)

number of cracks	BBFA0	BBFA20	BBFA10	NFA20
1	0.096	0.077	0.093	-
2	0.107	0.075	0.085	-
3	0.075	0.078	0.079	-
4	-	0.089	-	-
Average	0.093	0.080	0.086	-

4. Conclusion

Experiments were performed to evaluate the effect of fly ash on early-age cracking in concrete made of Portland cement with blast-furnace slag. Thermal cracking was detected by AE method. As a result, micro-cracking due to thermal change was observed, prior to drying shrinkage. AE activity detected implies that fly ash serves to reduce micro-cracking due to thermal change which occurred from 20 to 30 hours after casting concrete.

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