Investigation of Fire-damage in Concrete by Post-peak Control Technique Associated with Acoustic Emission

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Abstract

This paper presents a new test method to investigate the influence of fire-damage on stiffness, strength, toughness in macro-view and localization of micro-crack in micro-view of concrete by conducting uniaxial compressive test associated with acoustic emission (AE) after specimen subjected to heating with different thermos-conditions such as the rate of heating, maximum temperature, exposure time, as well as cooling condition. During the testing, the extensometer was used as feedback signal control to stabilize crack growth; the complete loading curve including pre- and post-peak stage was then obtained. Therefore, the evolution of AE microseismic sources with respect to loading process was also examined. The test results in macro-view show that the stiffness, strength and toughness decrease with an increase in maximum temperature; the post-peak behavior from snap back (Class II) convert to snap through (Class I) at maximum temperature ranged 200−400 ºC, whereas, in micro-view, the AE localization occurred earlier as the maximum temperature increased. When the maximum temperature reached to 600 ºC, the AE localization cannot be found during the uniaxial compressive test.

Keywords: fire-damage; concrete; uniaxial compressive test; acoustic emission

Nomenclature

M_{heat}	heating rate (ºC/min)
E_{time}	exposure time (min)
T_{max}	maximum temperature (ºC)
LL	load level (%)
$LL_{,L}$	load level of AE localization (%)

1. Introduction

Concerning reinforced concrete (RC) structure is the main system for buildings and constructions in Taiwan currently, the quality/quanity evaluation of fire-induced damage in RC structure is important for living safety. Tovey [1] proposed several methods such as color changing identifying of concrete, take core experiment, ultrasonic pulse (UP) measurement and the correlation of concrete strength reducing with temperature to evaluate the fire-damage degree. However, these methods were not widely used due to its' low accuracy [2]. In this study, to investigate the fire-damage characteristics of concrete, a uniaxial compressive test coupled with acoustic emission was developed and used after applying various heat-driven-damage treatments. In addition, to obtain the post-peak behavior of a uniaxial compressive test, the extensometer was used as the feedback signal control to stabilize fracture propagation.

2. Acoustic emission

When brittle materials encounter a change in their external environment, energy accumulates within the materials. When the absorbed energy reaches its threshold, it will be released with the contemporary formation of micro-cracks and internal damage. According to ASTM E610-82 [3], the AE phenomenon is defined as a transient elastic stress wave generated by rapid energy released from localized sources within a material, and employed as a nondestructive technique that can record the microseismic sources.

A significant contribution to AE detection was made by Kaiser [4]. When materials are reloaded, the AE signals only occur if the reloading stress is greater than the maximum. This so-called Kaiser effect has also been observed in rock in

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laboratory tests [5]. In recent years, the AE technique has been used to detect the location of micro-cracks for cement mortar and concrete material [6-8].

3. Fire-damage experiment

3.1. Fire-damage specimen preparation

The 70MPa strength concrete (high strength concrete) produced by Ya Tung Ready Mixed Concrete Corporation was used as the test material. Considering the size effect, end effect and AE energy declined distance. The specimens were fabricated into cubes of 50 mm × 45 mm × 120 mm as shown in Fig. 1 a. The cube specimens were then placed in oven with 105±5 ºC and stayed in 24 hours to lead void water dissipation. The prepared specimens were used to simulate fire-damage with different temperature conditions in high temperature oven (Fig. 1 b). When the fire-damaged specimen cooling down, the specimen was stored by vacuum packaging. In this study, the heating rate M_{heat} = 5 ºC/min, exposure time E_{time} = 300 min and maximum temperature T_{max} = 25, 200, 300, 400, 500, 600, 800 and 1000 ºC was conducted.

(a) (b)

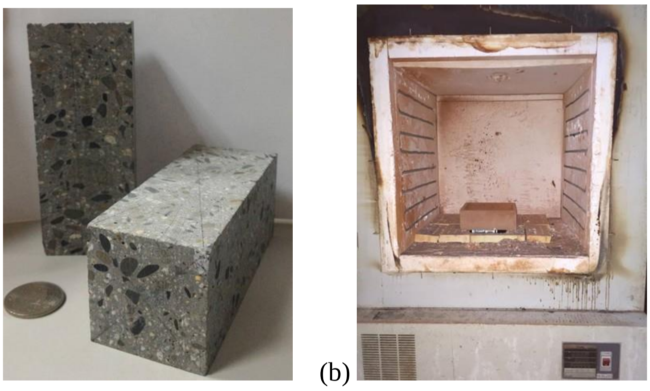


Fig. 1. Fire-damage concrete specimen preparation: (a) concrete specimen (b) high temperature oven.

3.2. Uniaxial compressive test

After fire-damage treatment, uniaxial compressive test was conducted. In this study, the multifunction, precision, high-stiffness servo-controlled hydraulic test system MTS 810 with capacity of 1MN output force was adopted as the load system. To obtain the entire loading curve, an axial extensometer (model 632.92F-05C, MTS Corp., Eden Prairie, MN, USA) and a roller chain as shown in Fig. 2 were used to stabilize the crack propagation. Data recorded by the extensometer indicates changes in the circumference of the specimen during the test. The length increment was used as a feedback signal to automatically control the load output.

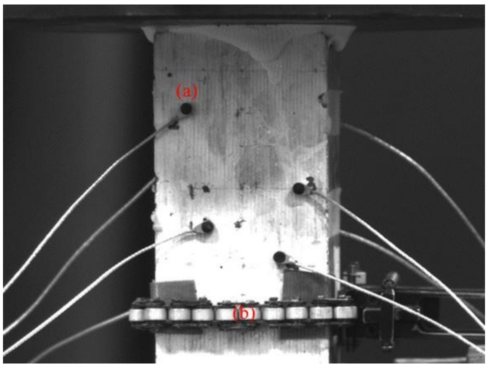


Fig. 2. Uniaxial compressive test coupled with AE for concrete: (a) AE sensor (b) extensometer.

3.3. AE system

Eight piezoelectric transducers (S9225, Physical Acoustics Corporation, Princeton Jct, NJ) was employed as the AE sensors in constructing the AE monitoring system. The sensors were attached to the specimen surface (Fig. 2), and the signals were received through the preamplifiers. The sampling rate and signal amplification of the data acquisition system were set to 8 MHz and 40 dB, respectively. The signals greater than the threshold of 7mv with a sonic rate between 100−1200 kHz were selected, and the minor voltage variations were recorded in a binary file. The collected binary data were used to identify the characteristics of the wave shapes, which determined the arrival time of the P-wave signal at each AE sensor.

4. Results and discussions

4.1. Relation of loading behavior and fire temperature in macro-view

Fig. 3 shows the complete loading curve with different maximum temperature obtained in this study including the pre- and post-peak loading processes. As expect, the stiffness, strength and toughness in general decreased with an increase in maximum temperature. The reduced ration of stiffness, strength and pre-peak toughness is shown in Fig. 4 a. At T_{max} = 200 ºC, the stiffness, strength and pre-peak toughness was not reduced significantly. When maximum temperature reached to 600 ºC, the stiffness, strength and pre-peak toughness was reduced as 79%, 71% and 61%, respectively. It should be noted that the post-peak behavior from snap back (Class II) converted to snap through (Class I) at maximum temperature ranged 200−400 ºC was observed (Fig. 3). Therefore, the post-peak toughness increased at T_{max} = 200−500 ºC (Fig. 4 b).

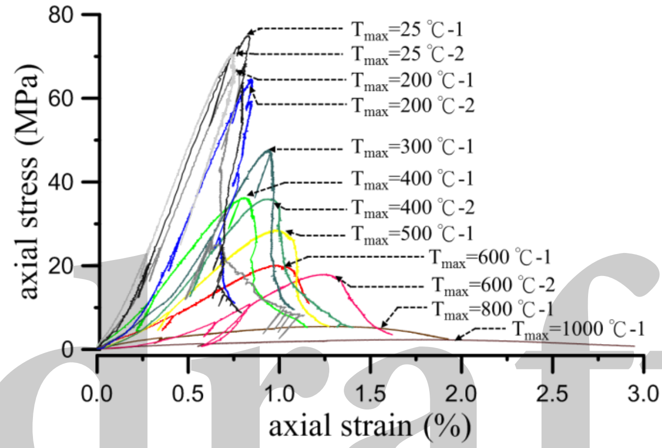
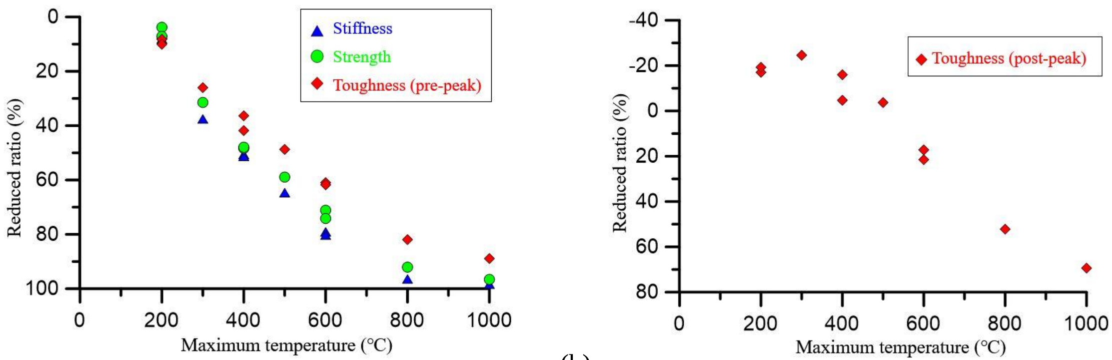


Fig. 3. Completed uniaxial compressive curves of concrete subjected to various temperatures.



(a) (b)

Fig. 4. Effect of fire temperature on stiffness, strength, toughness at pre-peak and toughness at post-peak.

4.2. Relation of AE evolution and fire temperature in micro-view

An AE event represents a microseismic crack occurrence, and the crack evolution is correlated to the loading process. In this study, an entire loading process was obtained; therefore, the whole evolution of the AE activities included occurrence, pause, reoccurrence, localization and growth could be investigated. Fig. 5 illustrates the relation between the loading process and the AE events of concrete subjected to fire-damage with T_{max} = 25 ºC. In Fig. 5, the solid and dotted curves present the macro-view (loading history) and micro-view (AE reactions) behaviors, respectively. Both curves have the same x-coordinate, which indicates normalized strain (defined as strain divided by strain at peak loading stress). The solid curve is the loading curve corresponding to the load level, LL (defined as loading stress divided by peak loading stress) on the left y-coordinate. Every point on the solid curve represents the occurrence of an AE event. The dotted line represents the correlation between the accumulated number of AE events and the normalized shear displacement.

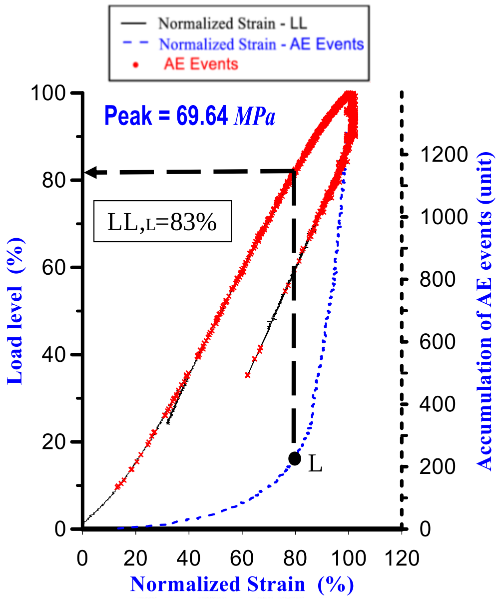


Fig. 5. Identification of localization by AE accumulated curve with respect to loading history (T_{max} = 25 ºC-1).

In Fig. 5, the accumulated number of AE events increased with the increasing normalized strain. According to the study of Chen [9], localization was defined as the phenomenon of AE events rapidly increasing, as at point L of Fig. 5. The position in which these events occur is correlated to the initial formation and propagation of the macroscopic cracks. Point L in Fig. 5 is the maximum curvature on the curve of the accumulated number of AE events; it shows the localization where LL is approximately 83%. Following the same method, the localization of the concrete subjected to fire-damage with different maximum temperature conditions (T_{max} = 25, 200, 300, 400, 500, 600, 800 and 1000 ºC) under uniaxial compressive tests can be found as shown in Table 1. As the maximum temperature increase, the localization of AE occurred earlier ($LL_{,L}$ decrease). However, when maximum temperature reached to 600 ºC, the AE localization cannot be found. This finding suggested that the AE localization may have occurred before the uniaxial compressive test conducted when the fire temperature is higher than 600 ºC.

Table 1. Summary $LL_{,L}$ of concrete subjected to fire-damage with different maximum temperature conditions under uniaxial compressive tests

Maximum temperature T_{max} (ºC)	Test No.	Load level at localization $LL_{,L}$ (%)
25	1	83
	2	-
200	1	80
	2	82
300	1	-
400	1	74
	2	-
500	1	62
600	1	Occurred at heating stage
	2	
800	1	
1000	1	

5. Conclusions

In this study, a uniaxial compressive test in conjunction with the nondestructive AE technique was developed to investigate the fire-damage characteristics of concert. A COD control technique was employed during testing to prevent unstable crack growth; a complete loading process and corresponding AE evolution therefore were obtained. The experimental results can be summarized as follows.

The stiffness, strength and pre-peak toughness decrease with an increase in maximum temperature. At maximum temperature ranged 200−500 ºC, the post-peak toughness increased with an increase in maximum temperature. Furthermore, the micro-crack localization occurred earlier as maximum temperature increased. The AE localization may have occurred before the uniaxial compressive test conducted when the fire temperature is higher than 600 ºC.

Acknowledgements

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