INVESTIGATION OF REPAIRING EFFICIENCY FOR CONCRETE CRACK USING THE EPOXY WITH LOW-PRESSURE INJECTION METHOD

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ABSTRACT: Concrete cracks always take place when it is subjected to excessive loads or exposed in severe environment. In consequence, the technique of crack reparation becomes inevitable for recovery of concrete. Epoxy-injection is the one used mostly in repairing concrete crack; while few research have been conducted to investigate the crack development as well as the efficiency of reparation for the crack. This paper presents the crack propagation, crack restoration and efficiency of reparation for various widths and depths of cracks.

KEYWORDS: Concrete crack, epoxy, repair.

1. INTRODUCTION

In the last decade, many catastrophic earthquakes attacked the regions around the Pacific-Rim, which made a great number of destructions of buildings and structures. This makes concrete industry have to face a severely challenge. The governments and researchers have to revise the building design codes and construction techniques. However, few researches have been conducted dealing with repair materials of their fundamental properties as being applied to concrete crack. For instant, fracture toughness of cracked concrete after being repaired which relates to crack initiation and may induce to deterioration of concrete should be paid more attention. On the other hand, traditional way to assess bonding strength of repaired concrete rarely evaluated a unique repaired crack [1]. Thus, it is difficult to compare different types of repairing material for their mechanical properties such as fracture toughness. It is felt more real and applicable to figured out those features by means of a unique real crack.

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From a fracture mechanics point of view, there is a fracture process zone in front of the crack tip of concrete as the crack propagates. Recently, Swartz and his coworkers [2-3] have used dye to reveal real crack front of concrete and found that crack front of concrete beam is not uniform through the beam thickness. Landis and Shah [3] have also found the same feature later by using acoustic emission method. It is felt valid to utilize dye technique and pre-cracked specimens to inspect the crack front of real crack and the profile of cracked section after being repaired.

On the other hand, traditional finite element technique has been commonly used to simulate the stress-strain behavior of solid or structure subject to exterior loading. However, it is restricted to a generous purpose only. For a real material, a crack always takes place as it is subjected to a load exceeding the strength of the material. Thus, dynamic finite element technique has been developed, in particular, in the research area of fracture mechanics. FRANC is the one developed in Cornell University and it has been polished and revised by Swenson et al [4]. It provides a good tool to engage dynamic analysis of material.

2. TESTING PROGRAM

The entire testing program comprises two types of concrete beam specimens. In portion I, beams are pre-cracked in three-point bending (TPB) or four-point bending (FPB) to create a unique crack. In portion II, beams are pre-notched with various depths and widths to simulate the cracks. The efficiency of reparation for concrete with various crack widths and crack depths has been carried out.

2.1 SPECIMEN PREPARATION

A unique mixture was adopted throughout the entire testing program. Quartzite is used as aggregates with the maximum grain size of 19mm. The water-cement ratio is 0.6. All beams had a unique dimension of 150 mm x 150 mm x 650 mm (span S = 600 mm). Four types of beams with 0, 1, 2 and 3 wire reinforcements being placed below the top surface of concrete beam were utilized to observe the distinction of crack fronts of concrete versus the wire reinforcements. All wires were cut off after the beam being pre-cracked, but prior to repairing. All beam specimens were cast in plywood forms and kept in these for 24 hours with a plastic sheet over the exposed surface. Companion 10 x 20 mm cylinders were made as well. All specimens were then de-molded and cured in a 100% humidity environment for 28 days. After, each beam was tested or pre-cracked. For those beams being cracked or pre-cracked, the crack is sealed first, followed by filling epoxy resin into the crack with low-pressure injection method. The width of two paired cracked surfaces of concrete is about 1 mm. Then, they were cured in the air for 7 days before being tested. For those pre-notched, each beam was notched in its middle with a designated depth and width. Three notch depths of 30 mm,
60 mm, 90 mm and three notches of 2 mm, 4 mm and 6 mm were adopted in this testing program.

2.2 TEST METHOD

All tests were conducted using a hydraulic loading system operating in load control and displacement control. The testing procedure comprises pre-cracking the beam specimen, inserting dye, filling the epoxy resin and then loading the beam to failure. For those beams being pre-cracked, as shown in Figure 1, the beam tests were loaded in a three-point bending or four-point bending setups to create a opening mode cracks or shearing mode cracks. The test configuration is thus designed according to a simulation analysis by a finite element code – FRANC 2D/L. The code was developed based on fracture mechanics, which could provide a means to predict the crack path of specimen. The cracks were repaired by epoxy later to investigate the efficiency of reparation.

3. TESTING RESULTS AND DISCUSSIONS

From the test results, it is observed that the efficiency of reparation is up to 134% in average for flexural cracks and is about 107% for shearing cracks, as shown in Fig.2 and Fig. 3. For those repaired pre-cracked beams, it can be seen in Fig. 4 that the repaired region of cracked section increases with the increase of crack depth, in terms of crack depth-to-beam depth ratio a/W. It also shows in Fig.5 that the reparation efficiency decreases with the increase of crack depth. This consists with the trend from the pre-notched beams as shown in Fig. 6 to Fig.8 that for a given crack width the repairing efficiency decreases with the increase of notch depth. On the other hand, the finite element code, FRANC 2D/L predicts a precise crack path, which is similar to that obtained from the test as shown in Fig. 9.

4. CONCLUSIONS

From the observation in the test, it showed that the number of wire reinforcements appear no big distinction on the profiles of crack fronts of concrete. It is also observed that for the plain concrete beams the efficiency of reparation of deeper crack is getting lower based on the epoxy with low-pressure injection method. On the other hand, a new crack face will be created after the old crack is repaired. The efficiency of reparation for flexural crack attains to 134%, higher than that for shearing crack which is attains to 107%. It implies that epoxy resin makes more efficient for restoration of flexural crack rather than that for shearing crack. For the pre-notched beams, it is found that the efficiency of reparation varies with notch depth, namely, the deeper the notch depth, the lower the efficiency of reparation, which is consistent with that found for the pre-cracked beams.
5. REFERENCES


Table 1 Repairing efficiency of concrete cracks

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Note: 1. $P_c$ and $P_r$ refer to cracking strength and repaired strength.

2. R.E. stands for repairing efficiency

(a) Three-point bending test  
(b) Four-point bending test

Fig.1 A Schematic sketch of load test configuration
Fig. 2 Strengths of TPB beams before cracking and after reparation

Fig. 3 Strengths of FPB beams before cracking and after reparation

Fig. 4 Profile of repaired cracked sections by epoxy injection for various crack depths
Fig. 5  Load strength of repaired pre-cracked beam for different crack depth

Fig. 6  Repairing efficiency of various crack depths for 2mm notch width

Fig. 7  Repairing efficiency of various crack depths for 4mm notch width

Fig. 8  Repairing efficiency of various crack depths for 6mm notch width
Fig.9 Real crack versus simulated crack predicted by FEM code