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DEFECT PROPAGATION EVALUATION USING ACTIVE MICROWAVE THERMOGRAPHY

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ABSTRACT

This research represents the application of active microwave thermography (AMT) to evaluate the propagation of defects in CFRP-strengthened concrete structures. In this paper, thermographic images of a CFRP-concrete joint tested under direct shear are analyzed to monitor and evaluate the propagation of an artificial defect created between a concrete block and an attached CFRP composite strip. This technique can be used by civil engineering researchers to study the propagation of defects during active loading and the effect on structural properties.

Keywords: active microwave thermography, defect propagation, CFRP-strengthened concrete

1. INTRODUCTION

Active microwave thermography (AMT) is a relatively new and efficient nondestructive testing and evaluation (NDT&E) technique that has recently shown promise for detection of defects in materials. Specifically, it has demonstrated strong potential in detecting different defects in cement-based materials [1, 2]. AMT is an integrated technique that utilizes a microwave heat excitation and subsequent thermal monitoring via a thermal camera. Like conventional thermography (in which the heat source is a flash lamp), AMT offers numerous advantages including inspection of relatively large areas, non-contact interrogation and inspection, and easy to interpret results. However, unlike conventional thermography (where a very short light pulse is radiated toward the inspection surface), in AMT, the heat source, i.e., microwave energy, is constantly applied over a relatively long period of time (typically a few minutes). As a result, AMT is a unique candidate for monitoring long-duration processes.

In this paper, AMT is introduced as a viable evaluation tool to inspect civil engineering structures that have been strengthened with externally bonded carbon-fiber-reinforced polymer (CFRP) composites and are challenging to inspect. Specifically, AMT is used to monitor interfacial debonding of CFRP-concrete joints with an artificial defect in direct shear tests. The premise is that as the microwave energy heats the CFRP-concrete interface, interfacial debonding and cracking disrupts the thermal diffusion and results in a local concentration of heat. The thermal profiles then are used to evaluate the propagation of any interfacial debonding. Representative test results are provided and indicate the strong potential of AMT for the aforementioned application.

2. MEASUREMENTS

2.1 Method

Fig. 1 (left) shows the test specimen, which is a concrete block with a CFRP composite strip bonded to one face. The CFRP composite, comprised of a single layer of unidirectional carbon fibers, is bonded to the concrete surface by epoxy resin. The ability to transfer load between the composite strip and the concrete block will be altered in the presence of defects that may result in formation and growth/propagation of interfacial cracking and debonding. This process may continue until complete failure of the specimen, as shown in Fig. 1 (right). As such, in order to investigate the ability of AMT to inspect such structures, an artificial defect is created in the test specimen by placing a plastic piece at a predefined location between the concrete and the composite, thereby creating a debonded region. The goal is then to monitor and evaluate the propagation of defects under active loading conditions. To this end, in Fig. 2, the direct shear test is schematically illustrated. In the single-lap direct shear test, shear stress is applied by pulling the end of the CFRP strip while the concrete block is restrained by a steel frame. Loading is controlled by monotonically increasing the displacement of the CFRP fibers relative to the concrete block at the loaded end until the CFRP composite debonds from the concrete and the CFRP and concrete separate.

The AMT portion of the experimental setup consists of a microwave source and amplifier, horn antenna, thermal camera, and control and image acquisition units, as is shown in Fig. 3.

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All measurements are conducted at a frequency of 2.4 GHz and a power level of 50 W. The horn antenna radiates microwave energy toward the specimen surface. The microwave radiation is absorbed by the specimen, subsequently causing a temperature rise over its surface. The horn antenna faces directly toward the specimen surface to maximize the microwave-induced heat over the surface. The distance between the antenna aperture and the specimen is 40 cm to ensure that the microwave excitation is sufficiently uniform over the inspection area while facilitating viewing of the inspection area with the thermal camera. Lastly, the control unit synchronizes the microwave illumination and thermal measurements.

2.2 Results

While illuminating the specimen with microwave energy, thermal images of the specimen surface are captured over time. The presence of defects, including a debonded region, yields a higher temperature rise relative to the sound ("healthy") regions of the specimen. Based on this, any discrepancies between the temperature rises over the surface thermal profiles are attributed to the effect of loading and formation and growth/propagation of defects. A significant difference between the temperature rise over defective and sound regions (called thermal contrast) corresponds to the existence of a defect.

In Fig. 4, the temperature rise profile over the surface of the CFRP strip are shown at different measurement times. The location of the artificial defect is indicated by a dashed white rectangle, with its center at approximately y = 120 mm (y is the vertical distance from the loaded end of bonded area). The failure, which was due to complete debonding of the CFRP strip from the concrete block, took place approximately 2400 sec from the onset of loading for this test. As seen, the defect has progressed from the top and bottom of the original location as a result of the applied shear stress. This result is in accordance to the expected (yet qualitative) mechanical response of the structure. In fact, parts of the structure adjacent to the defect have higher temperature rise, which may be attributed to local stress concentration caused by the initial defect.

3. CONCLUSION

The potential of active microwave thermography (AMT) for monitoring and evaluating defect growth/propagation in CFRP-strengthened concrete was successfully demonstrated experimentally. Specifically, a specimen with an artificial rectangular defect was tested under direct shear and monitored via AMT. Thermal contrast (TC) images were used to detect propagation of this defect during active loading. The results indicate that TC images can be used to monitor and evaluate the propagation of defects until failure.

FIGURE 1: CFRP-STRENGTHENED CONCRETE BLOCK BEFORE (LEFT) AND AFTER (RIGHT) FAILURE

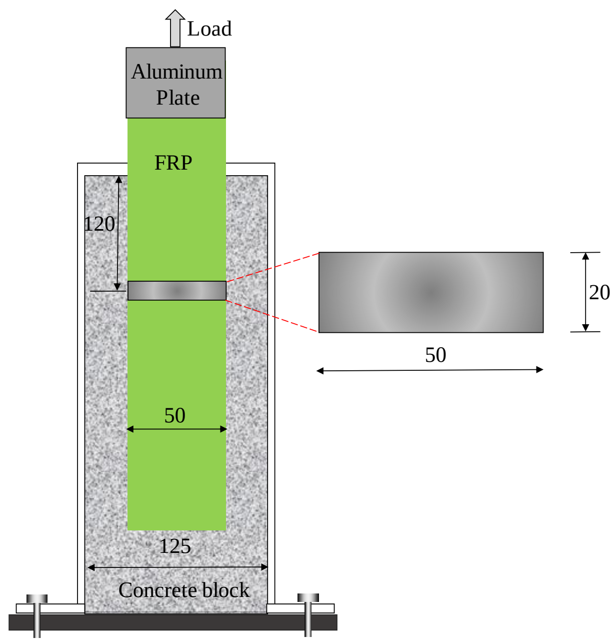

FIGURE 2: SCHEMATIC OF THE DIRECT SHEAR TEST WITH A DEFECTIVE SPECIMEN (DIMENSIONS ARE IN MILLIMETERS)

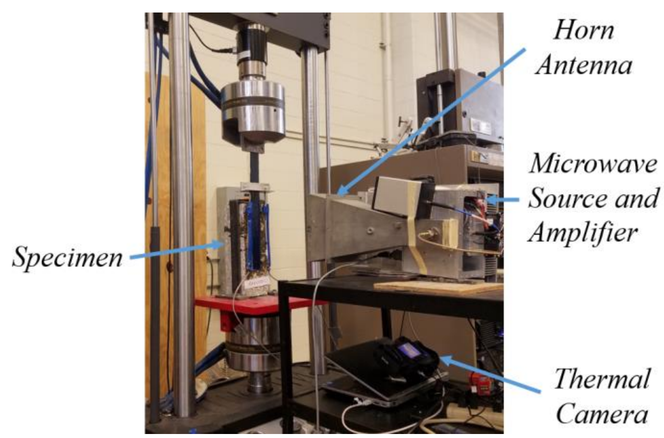

FIGURE 3: THE AMT EXPERIMENTAL SETUP

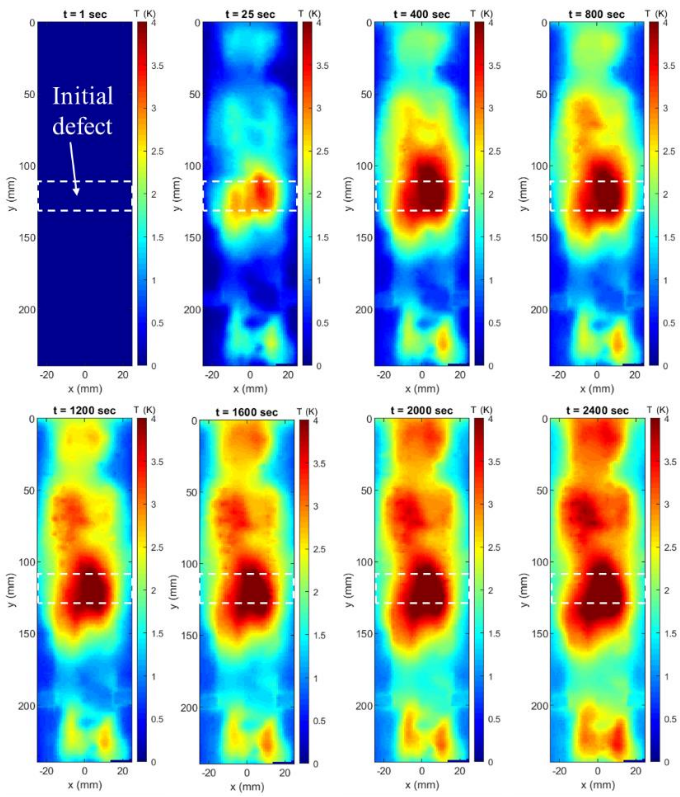

FIGURE 4: TEMPERATURE RISE PROFILE OVER THE COMPOSITE STRIP AT DIFFERENT TIMES

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REFERENCES

[1] Foudazi, A., Edwards, C. A., Ghasr, M. T., and Donnell, K. M., 2016, “Active Microwave Thermography for Defect Detection of CFRP-Strengthened Cement-Based Materials,” *IEEE Trans. Instrum. Meas.*, 65(11), pp. 2612–2620.

[2] Foudazi, A., Donnell, K. M., and Ghasr, M. T., 2014, “Application of Active Microwave Thermography to Delamination Detection,” *IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, Montevideo, Uruguay, May 12–15, pp. 1567–1571.

