# IR Thermography Analysis for the Structural Integrity Assessment of CFRP-Reinforced Concrete in Nuclear Containment Buildings

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## 1. Introduction

It is important to monitor the health condition of nuclear power plants to prevent the potential formidable issues induced by mechanical/structural/electrical failures. Periodic inspection of containment concrete structures is crucial for preventing leaks and long-term degradation. Infrared thermography (IRT) offers the advantages of being a non-contact method that is relatively easy to implement, yet its effectiveness is highly sensitive to heating conditions and timing of the visual observations [1,4]. Carbon fiber reinforced polymer (CFRP) is evaluated as a promising material to strengthen deteriorated concrete walls due to its superior strength-to-weight ratio, corrosion resistance, and ease of application. These advantages make CFRP a possible idea to extend the service life of containment structures. However, the performance of CFRP retrofitting relies on the integrity of the bond between the concrete substrate and the composite material [2, 3]. If debonding or hidden defects occur, the effectiveness of strengthening can be significantly reduced, making reliable inspection methods essential. In this study, short-pulse active IRT was applied to concrete specimens locally repaired with CFRP. The analysis emphasized that the thermal contrast between defective and intact regions is key to detectability [1,3]. The findings suggest that such contrast-based evaluation can provide a practical foundation for inspection strategies aimed at the long-term monitoring of containment structures, Additionally, it extends the use of IRT from surface crack detection to broader assessments of CFRP-strengthened containment buildings [4].

## 2. Experiments and Results

### *2.1. Experimental Methods*

Figure 1 shows the conceptual concrete wall of power plant. If there are some structural defects in concrete walls, there are thermal signals through concrete walls and liner plates by inner gases including air or water vapor leakage. For a simply test, we prepared the sample concrete wall and CFRP liner layer conducted under controlled boundary conditions using an environmental chamber. A high resolution LW camera (FLIR SC600) served as the imaging device, while a halogen lamp was employed as the external heat source (Figure 2) as a sun radiation. The standoff distance between the camera and the concrete specimen was fixed at 1 m, and the lamp was positioned 50 cm away at a 45 ° incidence angle. During the measurements, the ambient temperature and relative humidity inside the chamber were maintained at 20 °C and 30% RH, providing stable thermal conditions for repeatable observation.

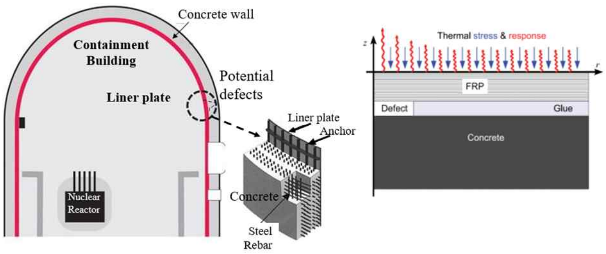


Figure 1. Configurations of defect in power plant and defect model with CFRP liner plate.

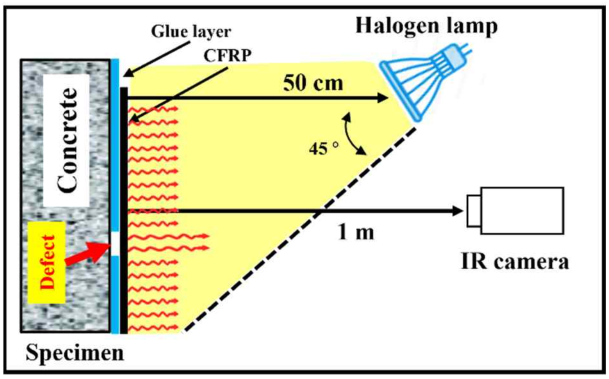


Figure 2. Experimental setup to detect the thermal contrast between defect and non-defect regions.

For specimen preparation, standard cement brick of dimensions 190 × 90 × 57 mm$^3$ were fabricated and tested. In 1$^{st}$ configuration, square polyethylene (PE) foam inserts with side lengths of 25 mm, 20 mm, and 10 mm were embedded at 50 mm intervals before applying a CFRP overlay. The PE foam was used to simulate air gaps because its thermal properties are close to those of air. In 2$^{nd}$ test configuration, two bricks of the same size were placed with a 2 mm gap between them, and the surface was subsequently reinforced with CFRP to simulate a linear crack. The specimens were subjected to short-pulse heating, with exposure times to the halogen lamp set at 15 and 30 seconds, followed by a cooling

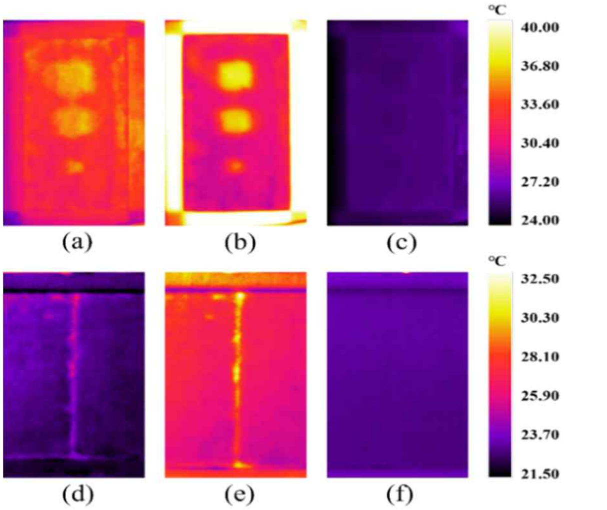


Figure 3. Temperature change of CFRP-strengthened specimens during active thermography. (a–c) Air-gap specimen at (a) initial heating, (b) after 15 s of heating, and (c) at the end of the 2-min cycle (d–f) Crack specimen at (d) initial heating, (e) after 15 s of heating, and (f) at the end of the 2-min cycle.

phase. The entire measurement cycle lasted for two minutes.

*2.2. Results and Discussions*

Figure 3 shows the thermal behavior of CFRP-strengthened specimens with crack and air-gap defects. Defective areas heated more quickly than the surrounding sound regions, creating a clear thermal contrast. This contrast is a clear evident after 15 seconds of heating, while nearly disappeared by the end of the 2-min cycle. Therefore defect/crack detection in concrete wall with a different heat transfer condition will be easily detected with a external heat source. Figure 4 shows the evolution of the thermal contrast $\Delta T$ between the defect area and sound regions under different heating durations. In the crack specimens, $\Delta T$ increased rapidly during heating, reached a peak just after heating ended, and then declined sharply, approaching zero within a 2-min cycle. The air-gap specimens exhibited a similar overall pattern, but the peak $\Delta T$ increased with larger gap sizes. Regardless of the type and size of the defect, all cases consistently showed that the strongest thermal contrast occurred during or immediately after heating and diminished quickly during the cooling phase.

## 3. Conclusions

This study tested and evaluated the effectiveness of infrared thermography (IRT) for detecting crack and air-gap defects in CFRP-strengthened concrete specimens. Defective regions heated faster and showed greater thermal contrast than sound areas, but this contrast diminished quickly during cooling, indicating that the optimal detection window is during or just after heating.

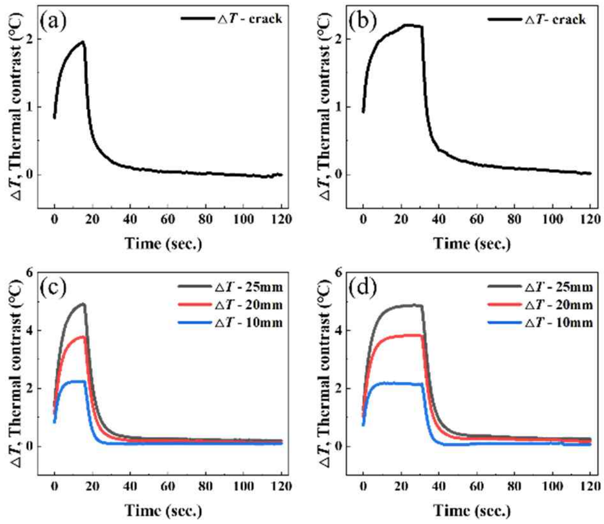


Figure 4. Thermal contrast ($\Delta T$) between defective and sound regions in (a) crack specimen after 15 s heating), (b) after 30 s heating, (c) air-gap specimens after 15 s heating, gap sizes 10–25 mm), and (d) air-gap after 30 s heating.

Even short-pulse heating of 15–30 seconds produced detectable contrast, confirming the practicality of IRT for rapid inspection. These results highlight the need to optimize heating parameters and observation timing, and demonstrate that IRT is a practical, non-destructive technique with strong potential for early detection of structural health monitoring of CFRP-strengthened containment structures and autonomous detection.

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