Emerging Technologies

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

Boundary and size estimation of debonds in external wall finishes of high-rise buildings using Infrared thermography

Wallace W.L. Lai and C.S. Poon
Department of Civil and Environmental Engineering
Hong Kong Polytechnic University, Hong Kong

ACI Fall Convention
Toronto 2012

Introduction

- Issues about building durability and safety are very important.
- How can infrared thermography fit into this issue?

Acknowledgement

• Innovation Technology Fund, Innovation Technology Commission, Hong Kong Government
• Assistance of colleagues Mr. K.H. Wong, Ms. Zhang B.Y. and Mr. Zhan B.J. for building up of specimens and data collection.

Diagnosis of external wall envelop

• Visual inspection:
  - relies on visual identification of surface defects to predict internal conditions of structures.

• Hammer tapping:
  - requires erection of scaffolding.

• Pull-off test
  - requires erection of scaffolding and destructive coring of samples
Diagnosis of external wall envelop

- NDE-CE methods (such as infrared thermography) are non-destructive, effective and cover a large area. It serves as a screening tool before rational coring schemes are decided for destructive tests on material properties.

Visual inspection/destructive test → NDE inspection

Current nondestructive evaluation techniques for external wall evaluation

Traditional methods
  - Visual inspection
  - Hammer tapping after scaffold erection
  - Pull-off strength test

Relatively new methods
  - Passive qualitative infrared thermography
  - Passive quantitative infrared thermography (QIRT)

Note: QIRT means boundary and size measurement but not absolute temperature in this context.

Detection of falling tiles by passive infrared thermography - principles

Because of the air void insulation, the heat dissipates in different rates:

- Warmer area
- Cool area

Qualitative identification of tile debond from buildings by passive infrared thermography

One of the problems in passive qualitative IR survey: arbitrary temperature scale

Temperature distribution obtained by infrared thermo-imager
From traditional to passive qualitative IRT to quantitative IRT methods

1. Ineffective traditional quantitative destructive methods: Pull-off and hammer tapping require scaffolding and tedious labour works.

2. Mandatory building inspection scheme

Under the MBIS, owners of buildings aged 30 years or above (except domestic buildings not exceeding 3 storeys) will be required to carry out inspections (and, if necessary, repair works) of the common parts, external walls and projections of the buildings once every 10 years.

3. Cost estimation in rehabilitation scheme in housing estates

4. Qualitative IR bases on subjective adjustment of temperature scale cannot provide extent of damage

Two inadequacies in current IR survey in the recommended test methods published by HK Concrete Institute

1. Qualitative, not quantitative

2. Many parameters are not back-up by research, such as limitation of wind speed, angle of incidence between the IR camera and wall, etc.

3. Indexing of severity due to debond not available

Passive QIRT on boundary and size estimation of debond

Focus of the study:

- Digitized greyscale images (in temperature or pixel values) but not colored non-linear images

- 2D spatial analysis of the temperature or pixel profiles by robust computer programs

- Definition of physical boundary of the debond by temperature or pixel profiles

- Understanding of the variables affecting the methods and algorithms

The objective of the project is to formulate a code of practice to be used in industry.

Preliminary development of QIRT methodology based on lab and field works

1. Instrumentation designed for per-minute image capture of IR images in normal-angle experiment

Variables

<table>
<thead>
<tr>
<th>Environmental</th>
<th>Changes of heat intensity in sunny and cloudy days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct or oblique angle of exposure to sunlight</td>
</tr>
<tr>
<td></td>
<td>Wind speed</td>
</tr>
<tr>
<td>Material</td>
<td>Heat transfer properties, such as thermal conductivity</td>
</tr>
<tr>
<td></td>
<td>Emissivity of surface materials</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>Different illumination angles of the infrared thermo-imager on the tested surface</td>
</tr>
<tr>
<td></td>
<td>Types of infrared thermo-imager</td>
</tr>
<tr>
<td>Measurement</td>
<td>Definition of defect boundary</td>
</tr>
<tr>
<td>Algorithm</td>
<td></td>
</tr>
</tbody>
</table>

Preliminary development of QIRT methodology based on lab and field works
preliminary development of QIRT methodology based on lab and field works through software program

1. LabVIEW program designed for per-minute image capture of IR images in normal-angle experiment

Experiment

- FLIR SC3000 infrared camera (spectral range 8-14μm)
- Grayscale IR Images captured once in every 15 minute
- Six plastic foam plates at different cover depths of the rendered concrete. Covers of the foam plates are indicated in the figure to the left. Thickness of render is about 25mm.
- Specimens exposed to direct sunlight.
- Temperature scale dependent on the intensity of sunlight at the time of experiment.

Analysis step 1: Extraction of ROI in grey-scale IR images and mean filter of images

Extraction of region of interest (ROI) from debond ID 1-6

Analysis step 2: Vertical (y-y) and horizontal (x-x) segments of the pixel profile within the ROI

Vertical segment at the centre of the debond

Analysis step 3: migration of grayscale to binary IR images in vertical and horizontal segments

Combined binary thermogram which contains numbers of white (debond) and black (intact) pixels

Analysis step 4: Computation of the debond area

0.45m = 7 pixels

- Scale the thermogram to physical size by known distance between objects to number of pixels on the image
Hot day’s example

Results:
1. All foam plates at different cover depths are measurable
2. Foam plates at cover depths 27.3 and 20.3mm yield the largest error

Known size of the debond = 44.2cm²

Cold day’s example

Results:
1. Foam plates at cover depths larger than 7.9mm are not measurable

Known size of the plastic foam = 44.2cm²

Standard deviation and % error of the measured and actual size of foam plates

<table>
<thead>
<tr>
<th>Known size (cm²)</th>
<th>16.7</th>
<th>16.8</th>
<th>16.9</th>
<th>17.0</th>
<th>17.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured size (cm²)</td>
<td>16.8</td>
<td>16.9</td>
<td>17.0</td>
<td>17.1</td>
<td>17.2</td>
</tr>
<tr>
<td>% error</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

% error in general < 10%

Further works in progress
(2) Oblique angle of illumination

Conclusion

- Current results have proven to yield high accuracy. Optimizations of algorithm and accuracy check with environmental, material and instrumentation’s variables are in progress.
- It does not require extra data collection procedure compared to the qualitative IRT method which has already been regularly used.
- A code of practice about the QIRT method to measure debond size will be published to fit the requirement of the lately legislated building inspection scheme implemented by the HK Government.

Further works in progress
Effect of Viewing Angle

Conclusion