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Prof. C.S. Poon, obtained his PhD in Environmental Engineering from Imperial College, London University. He is currently Professor and Director of Research Centre for Environmental Technology and Management at the Civil and Structural Engineering Department of the Hong Kong Polytechnic University. Prof. Poon specializes in the research and development of environmentally friendly construction materials, waste management and recycling technologies, and has published over 250 papers in international journals and conferences.

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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

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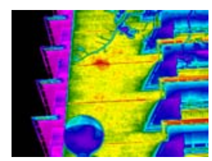


Introduction

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

Diagnosis of external wall envelop

- Visual inspection:
  - relies on visual identifcation 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

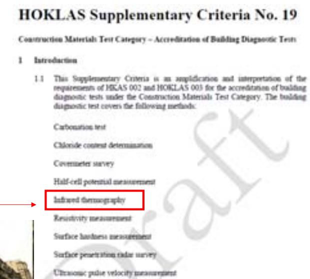
- NDE-CE methods (such as infrared thermography) are non-destructive, effective and cover a large area. It serves as a screening tool before rational coring schemes are decided for destructive tests on material properties.

Visual inspection/ destructive test → **NDE inspection**

Mandatory Building Inspection Scheme (MBIS) which is a law → The Hong Kong Laboratory Accreditation Scheme (HOKLAS) which is a practice under ISO 17025

The Buildings (Amendment) Ordinance 2011

- Require building owners to carry out regular building inspections and repair works in respect of their buildings
- Cover private buildings aged 30 years or above, except domestic buildings not exceeding three storeys in height
- Building owners will be required to carry out an inspection once every 10 years
- Areas to be inspected: common parts, **external walls**, certain projections and signboards of a building



HOKLAS Supplementary Criteria No. 19

Construction Materials Test Category – Accreditation of Building Diagnostic Tests

1 Introduction

1.1 This Supplementary Criteria is an amplification and interpretation of the requirements of HKAS 002 and HOKLAS 003 for the accreditation of building diagnostic tests under the Construction Materials Test Category. The building diagnostic test covers the following methods:

Carbonation test

Chloride content determination

Covermeter survey

Half-cell potential measurement

Infrared thermography

Resistivity measurement

Surface hardness measurement

Surface penetration radar survey

Ultrasonic pulse velocity measurement

Draft

Current nondestructive evaluation techniques for external wall evaluation

Traditional methods

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

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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

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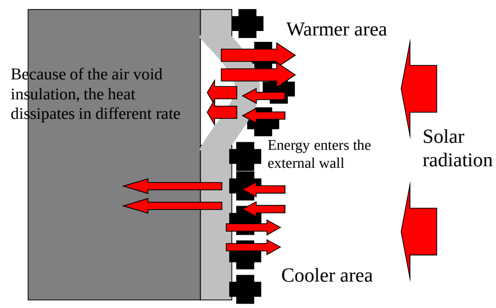
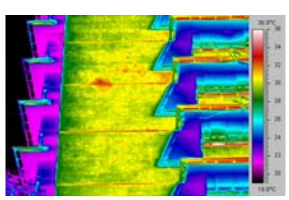
Detection of falling tiles by passive infrared thermography - principles



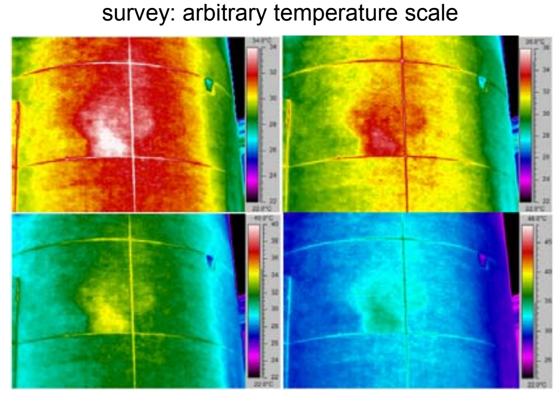
Qualitative identification of tile debond from buildings by passive infrared thermography

Visual photo



Temperature distribution obtained by infrared thermo-imager

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



From traditional to passive qualitative IRT to quantitative IRT methods

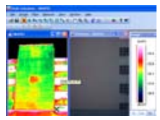
1. Ineffective traditional quantitative destructive methods: Pull-off and hammer tapping require scaffolding and tedious labour works.

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



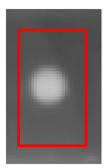
Two inadequacies in current IR survey in the recommended test methods published by HK Concrete Institute

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



Focus of the study under a Hong Kong government funded project

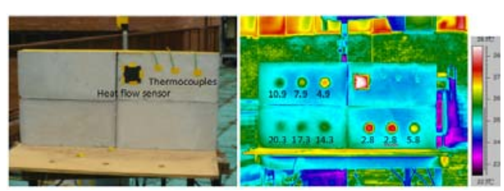
	Variables
Environmental	Changes of heat intensity in sunny and cloudy days
	Direct or oblique angle of exposure to sunlight
	Wind speed
Material	Heat transfer properties, such as thermal conductivity
	Emissivity of surface materials
Instrumentation	Different illumination angles of the infrared thermo-imager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

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

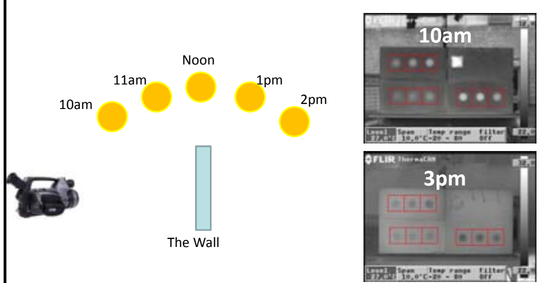
1. Instrumentation designed for per-minute image capture of IR images in normal-angle experiment

Preliminary development of QIRT methodology based on lab and field works

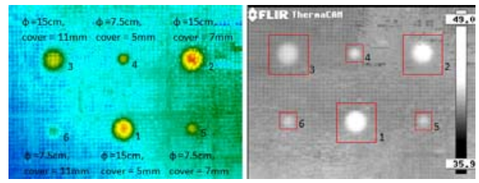


preliminary development of QIRT methodology based on lab and field works through software program

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

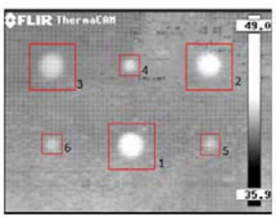


Experiment



- 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

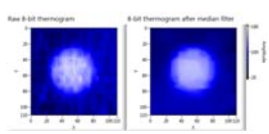
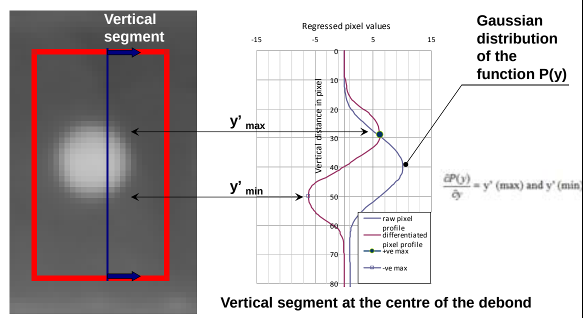


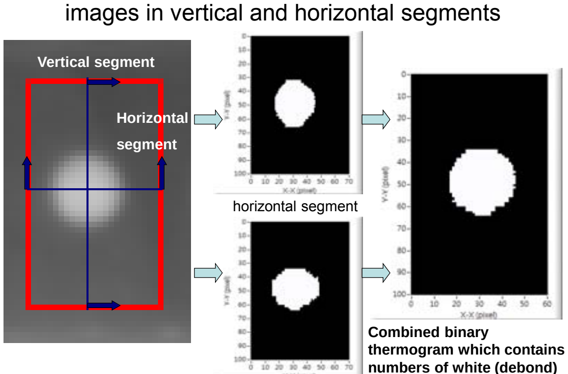
Image median filter

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

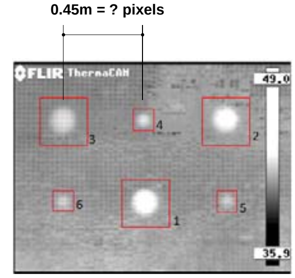
Analysis step 3: migration of grayscale to binary IR images in vertical and horizontal segments



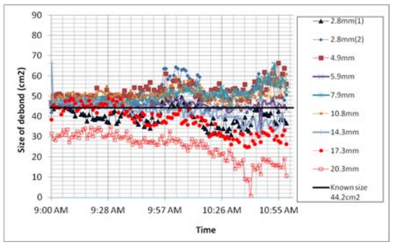
Combined binary thermogram which contains numbers of white (debond) and black (intact) pixels

Analysis step 4: Computation of the debond area

- Scale the thermogram to physical size by known distance between objects to number of pixels on the image



Hot day's example

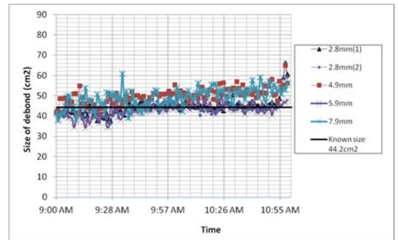


Results:

1. All foam plates at different cover depths are measurable
2. Foam plates at cover depths 17.3 and 20.3mm yield the largest error

Known size of the debond = 44.2cm^2

Cold day's example



Results:

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

Known size of the plastic foam = 44.2cm^2

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

Debond ID		1	2	3	4	5	6
Diameter of debond (cm)		15	15	15	7.5	7.5	7.5
Size of debond (cm^2)		176.7	176.7	176.7	44.2	44.2	44.2
Cover depth (mm)		5	7	11	5	7	11
Time	Temperature range (°C)	Measured sizes of debond (cm^2)					
1030	33.9 - 44	169.6	199.2	166.3	49.8	-	-
1045	33.9 - 44	165.5	172.9	166.4	48.7	-	-
1100	33.9 - 44	163.6	192.8	174.4	49.5	-	-
1115	37.1 – 45.9	172.4	162.0	175.6	43.4	-	-
1130	37.1 – 45.9	165.9	192.7	169.4	44.7	-	-
1145	37.1 – 45.9	166.4	157.2	169.6	42.2	-	-
1200	35.9 – 49	171.5	164.8	178.1	38.3	-	-
1215	35.9 – 49	169.6	169.9	174.3	42.3	-	-
1230	35.9 – 49	166.5	163.2	174.1	44.1	-	-
1245	35.9 – 49	167.7	163.9	168.0	40.5	-	-
1300	35.9 – 49	164.6	172.1	171.5	43.0	-	-
1315	35.9 – 49	169.6	165.6	183.9	42.2	-	-
RMSD		**2.8**	**14.0**	**5.2**	**3.6**	-	-
% error		**1.6**	**7.9**	**2.9**	**2.0**	-	-

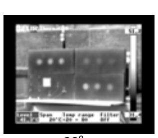
% error in general < 10%

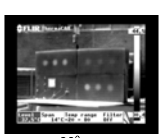
Further works in progress

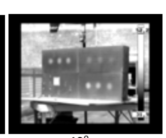
(2) Oblique angle of illumination

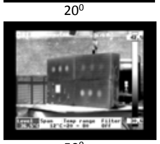
Further works in progress

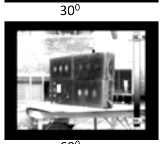
Effect of Viewing Angle

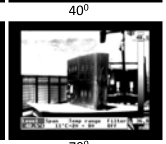

20^0


30^0


40^0


50^0


60^0


70^0

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.