The use of the IRT to assess Steel and FRP hybrid elements

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ABSTRACT: Infrared thermography has been used in engineering as non-destructive testing method for various applications. In civil engineering, it is mainly used to diagnose and assess structural defects and thermal insulation in residential and commercial buildings, cracks and cavities in concrete structures. With the increase of the usage of fiber reinforced polymers (FRP) in civil engineering for strengthening of concrete structures and for development of new FRP and hybrid steel/FRP elements, it is important to analyse delamination and debonding with non-destructive method.

1 INTRODUCTION

This paper investigates the applicability of the infrared thermography (IRT) for evaluating structural condition of hybrid steel/FRP elements on basis of the experimental studies conducted at Kingston University London.

Medium scale hybrid steel/FRP shear wall was tested under quasi-static loading. Paper investigates the process and extent of development of delamination and the heat released due to the plastic deformations during process of loading. It demonstrates the range of the IRT applications and possible methods and approaches for analysing the obtained data.

2 BACKGROUND

2.1 IRT

Infrared thermography (IRT) is a remote mapping system which creates infrared images via absorption and distribution of radiated heat over the investigated element/structure. Objects with a temperature above absolute zero (-273.15^{o}C) emit electromagnetic radiation in the infrared region of electromagnetic spectrum, which is detected by infrared (IR) camera. Infrared thermography provides a real-time pseudo colour coded image of the object, allowing to investigate different types of structures and to monitor their condition in a quick and cost-effective way (Bagavathiappan et al., 2013).

Origins of infrared thermography (IRT) go back to the early 1800s, when Sir William Hershel discovered thermal radiation beyond the deep red in the visible spectrum. In 1880, first IR photographic image was obtained by William de Wiveleslie and first IR mono-detector camera was produced. Since that time IRT was used in many disciplines like engineering, medicine and agriculture, however it was highlighted that IRT is still not adequately known as industrial instrumentation and its application can benefit a lot of potential users (Meola, 2012).

2.2 IRT and use of the IRT in the civil engineering

2.2.1 Building diagnostics of thermal envelope

IRT has been used to conduct building diagnostics for many years. Non-destructive and non-contact testing of the building elements is a quick method to check thermal energy of the whole structure. It can detect energy leaking from a building's envelope, missing or damaged thermal insulation in walls and roofs, air leakages around openings and moisture damages (Balaras and Argiriou, 2002). However, as there is an interaction between indoor and outdoor environment, it is better to perform and energy building audit at night or during a cloudy day in order to minimize heat losses.

2.2.2 Defects in concrete and masonry structures

Active IRT technologies like impulse thermography and lock-in thermography were developed to investigate inhomogeneities in the structural elements near surface regions. For impulse thermography, surface of the object is heated by IR radiator and heating and cooling down processes are recorded. Differences between temperature transient curves would allow determining defects like voids in concrete or masonry structures (Maierhofer et al., 2007). Experimental and parametric studies demonstrated that this method is effective for concrete covers up 10 cm deep (Maierhofer et al., 2005). Hidden defects at various depths in concrete specimens by investigated by Cheng et al. (2008), IRT images clearly identified locations of the defects; however their depths were quantified with better precision using elastic wave methods.

2.2.3 IRT use in composite materials

Fibre reinforced polymers (FRP) have been popular in the last decades to repair and strengthen concrete structures. A number of studies were conducted to assess the integrity of the bond between concrete and FRP, delamination of FRP and any detects occurred during laying-up and curing of FRP laminates.

Reinforced concrete beams strengthened with carbon FRP were tested in flexure and shear failure modes by Levar et al. (2003). In comparison to acoustic sounding, IRT detected 25% more of the voids introduced before the test and IRT was proved to be an effective non-destructive way to evaluate bonding of FRP and concrete during the test as well.

Donchev et al. (2013) conducted an experimental study on concrete beams strengthened with carbon FRP and basalt FRP wrapping. Different types of defects were introduced in the bond layer. IRT detected the size and geometry of the defects in an effective and quick way.

Petkune et al. (2013) provided classification in use of the IRT in civil engineering area and IRT use to assess steel shear wall wrapped with glass fibre reinforced polymers (GFRP). This paper contains results of the further tests conducted at Kingston University London on the use of the IRT to monitor condition of hybrid steel/FRP shear wall and its analysis.

3 METHODOLOGY

3.1.1 IRT camera specifications

To conduct test VarioCAM high resolution infrared (IR) camera was used which is capable to measure temperatures between -40°C to 1200°C. This camera used for a long wave infrared spectral range (LWIO) of 7.5- 14 µm and a resolution of 640 x 480 pixels. To record data and analyse results Irbis software was used. Figure 1 shows an IR camera set-up for recording.

Figure 1. IRT camera set-up

3.1.2 Description of the experimental set-up and specimens tested

Medium scale hybrid carbon FRP and steel shear wall (HCSW) was tested under quasi-static loading. Shear wall was made of steel frames of UB127x76x13 section and hybrid infill plate. HCSW specimen had an infill plate consisting of the steel plate laminated with carbon FRP (CFRP) material on both sides at 45° inclination of fibers.

HCSW was tested under quasi-static loading with an increase of the horizontal in-plane displacements from 0.4 mm to 30 mm at the level of the top part the shear wall. IR camera was set up on one side of the shear wall specimen and it was used in two ways: passive thermography without external heat and active thermography with external heat.

4 ANALYSIS OF THE RESULTS

4.1 Passive IRT: heat release

Passive thermography was used to measure surface temperature of the specimen continuously and recording images at 30 seconds interval during the testing. No external heat was applied during the test. As the displacement was increasing, IR camera was recording temperature changes due to the developed plastic deformations occurring in the specimen. Figure 2a shows an image of HCSW specimen displaced by 30 mm in horizontal direction in regards to neutral position. Figure 2b shows IR image and temperature distribution with increase of the temperature in the direction of the diagonal tension field during the process of testing of the sample.

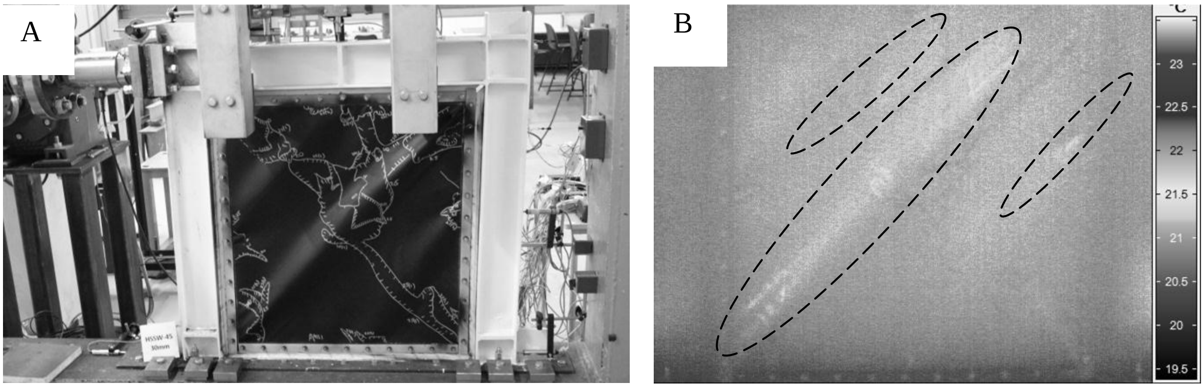

Figure 2. Heat releases at maximum 30 mm displacement in horizontal direction for HCSW-1 specimen a) shear wall photo b) IR image

By using MATLAB software further analysis can be made by identifying a temperature profile along diagonal tension field line 1-1 (figure 3a). This method can be used for estimation of the temperature increase along the diagonal tension field for applied displacements and to assess the magnitude and the distribution of plastic deformations.

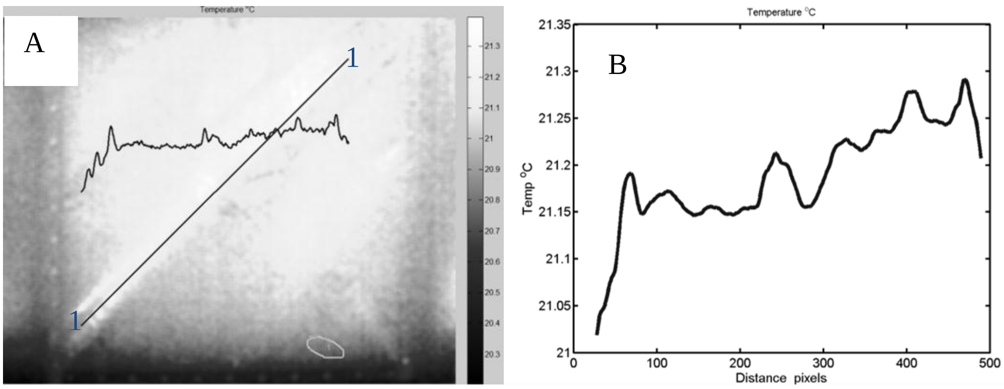

Figure 3. IR images of HCSW-1 specimen at 30 mm displacement after MATLAB processing a) temperature distribution b) tensile field profile

Figure 4 shows lower temperatures at the bottom of the shear wall, where it is fixed and increase of the temperatures along diagonal profile. Warmer areas around bolts indicate friction and plastic deformations around bolted connection between shear wall frame and infill plate. As connections between frame and infill plate elements are crucial in shear wall design, IR camera allows to detect when friction in the bolt area begins and to monitor further development of plastic deformations till failure of the connection.

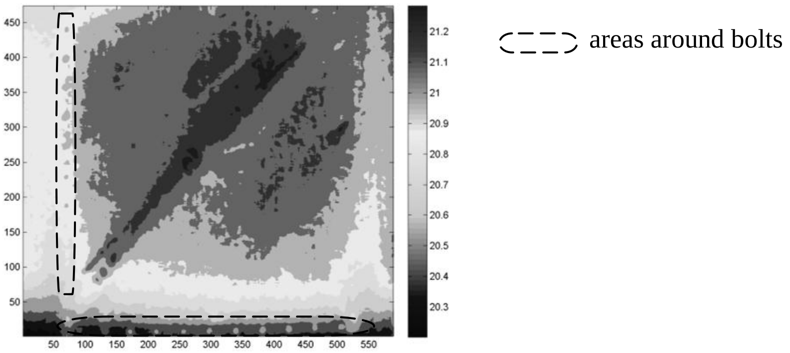

Figure 4. IR images demonstrating temperature distribution

The results from passive IRT are clearly defining the opportunity to assess the increased plastic deformations on basis of generated temperature differences for steel and hybrid structural elements and the connections between them during the process of testing.

4.2 Active IRT: Analysis of the delamination

Active thermography was used to measure the surface temperature of the specimen after exposure to external heat. Heat guns were used to apply additional thermal excitation. Due to irregular geometry of the sample heat gun was adopted as more appropriate source of heating than some alternative sources like thermal blanket.

The active thermography was conducted after application of the certain range of the displacement to the shear wall specimen. An external heat provided a thermal contrast between the areas of bonding of the steel and FRP materials and characterizing bond's integrity.

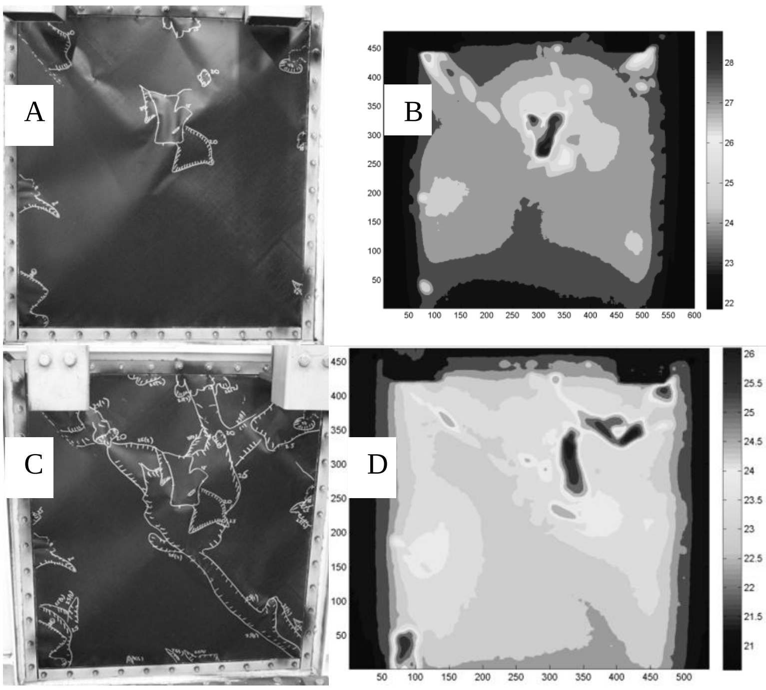

Figure 5. Delamination detection for HCSW specimen (a and b at 20 mm displacement; c and d at 25mm displacement)

Comparison and estimation of the delamination was conducted via two methods in parallel: visual inspection (figure 5 a and c) and IR images (figure 5 b and d). Via visual inspection the estimated areas of FRP debonding from steel plate at 20 mm displacement were 10% and at 25 mm displacement were 35%. The analysis of the results from IRT was conducted limiting the area of the sample to part with similar thermal mass (internal zone of the infill plate) and assuming $1^{o}C$ as temperature difference between the areas with damaged and undamaged bonding within this zone. Corresponding results for the same level of displacement as for visual inspection are 19% and 45%. Those results are considered as more reliable having in mind lower precision of visual inspection and further development of damaged zones as result at higher levels of loading.

5 CONCLUSIONS

- IRT has a potential use in NDT testing in investigation of delamination in hybrid steel/FRP structures with higher precision than visual inspection.
- Passive IRT could be successfully used for estimation the behavior of steel elements and their connections during the process of testing.
- The application of both active and passive thermography in combination with MATLAB analytical processing allows for better precision and higher reliability of the obtained results.

6 REFERENCES

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