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Application of IRT for assessing the process of delamination of hybrid steel/FRP elements

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ABSTRACT:
IRT (Infrared Thermography) has been used for a wide range of applications in Civil and Structural engineering including the analysis and assessment of structural members of a building with surface temperature as a key parameter. IRT allows for detection of delaminated surfaces and assessment of the integrity of a structural member to an extent which cannot be seen by the naked eye. Delamination of fibre reinforced polymer (FRP) laminates from a steel plate in a hybrid steel/FRP infill plate system contributes to a reduction in load capacity, and thus identification of location and extent of delamination is an integral part in assessing damage.
The presented paper investigates, analyses and compares the experimental IRT results for different combinations of hybrid 'FRP and steel' infill plates that are subjected to application of quasi static load following ATC 24 protocol. The obtained results will aid in estimating the delamination behaviour of hybrid steel / FRP infill plates in steel shear walls during the process of cyclic loading. Conclusions on the applicability of the use of IRT to identify the location and extend of delamination are offered.

1 INTRODUCTION AND BACKGROUND

Fibre Reinforced Polymers (FRP) is one of the most promising advances in the Civil Engineering Industry. FRP today is not only used as an alternative material for construction industry, but also for the strengthening as well as repairing of existing structures. The main advantages Fibre Reinforced Polymers have over the use of conventional steel are the higher strength to weight ratio and higher corrosion resistance along with environmental degradation resistance.
The aim of the project is to investigate the behaviour, to analyse and compare the capacity and the energy dissipation in Hybrid Infill Plates for Shear walls and to investigate the process of delamination using Infrared Thermography.
Steel shear wall (SSW) is a well-known lateral opposing framework and has been utilized as a part of the construction business since the 1970s.

Infrared thermography (IRT) is a remote mapping framework which creates infrared pictures by means of retention of infrared radiation as heat is distributed with time. It permits to distinguish and to assess the imperceptible radiation transmitted by various imaging system over infrared radiation into a visible picture.
IRT method can be connected to analyses defects in the association between reinforced cement beams and CFRP laminates utilized for strengthening (Donchev et al., 2013). During examination a high-resolution VarioCAM infrared camera was utilized. The infrared picture is obtained by applying heat from a heat gun.

The energy dissipation in hybrid shear walls is developed in three different areas; the steel frame, the hybrid infill plate and the connection between them. Cut outs in infill shear panels is an important factor that influences energy dissipation and ultimate load capacity, as assessed by Maleki (2010). It was concluded that the stiffness, energy dissipation and load carrying capacity decrease for specimens with cut-outs. Maleki added that this issue could be resolved via the application of additional stiffeners.
The utilization of hybrid infill plates, produced using fibre reinforced polymers (FRP) and steel materials, could be considered as a powerful opportunity to limit deformations and increment the firmness of the framework. As a continuation and further advancement of the research, experiments have been developed to examine the conduct of hybrid carbon/glass FRP and steel samples (Petkune et al., 2013).
Previously, analytical assessment of SSWs strengthened with GFRP/CFRP laminates had been carried out (Nateghi-Alahi et al., 2013). The authors implemented the application of GFRP/CFRP laminates consisting of two and four layers of GFRP/CFRP on either side of the specimen. The orientation of the fibres in each specimen was ±45° or 0° and 90°.
A research was conducted by Petkune et al. (2014) in which investigation was done for the effects of variation in hybrid and FRP plates. It was found that there was a major improvement in resistance when adhesive was used around bolted area. The research conducted at the moment is mainly concentrating on how to improve the dissipation of energy in connections.
A state-of-the-art review by Zhao et al. (2014) reviled that the exposure to UV light decreases the bond strength by 20%, bond strength reduces significantly when temperatures exceed the glass transition temperatures and large deformations in cyclic lading reduces the bold between the FRP and steel. Environmental effects of the bond between FRP and steel has also been reviewed by Bai et al. (2014) and Borrie et al. (2016).

2 METHODOLOGY

2.1 Specimen

2.1.1 Sample 1 – CFRP without adhesive (4CSSW)

The 4CSSW sample used in the experiment is a hybrid infill plate which includes a steel plate laminated on either side symmetrically with a total of four layers of unidirectional Prepreg CFRP supplied by TenCate Advanced Composites UK each at alternate orientation of +45° and -45°. For the preparation of the infill plate before testing, the steel plate had been abraded using a sandpaper and then cleaned with acetone to achieve a rough and clean surface. The hybrid infill plate was sealed in a vacuum bag between two plates and then placed into the oven as per curing specifications.

2.1.2 Sample 2 – GFRP with adhesive (4GSSWA)

The 4GSSWA sample used in the experiment is a hybrid infill plate which includes a steel plate laminated on either side equally with a total four layers of unidirectional Prepreg GFRP each at alternate orientation of +45° and -45°. The method of preparation is as Sample 1 above with an additional layer of adhesive film EF72 applied on either side of the steel plates to increase the bond between the FRP and steel elements. The general idea of the application of the unidirectional FRP can be seen in Figure 1.

2.1.3 Sample 3 – GFRP without adhesive (4GSSW)

The 4GSSW sample used in the experiment is a hybrid infill plate which includes a steel plate laminated on either side equally with a total of four layers of unidirectional Prepreg GFRP each at alternate orientation of +45° and -45°. The method of preparation is as Sample 1 above.

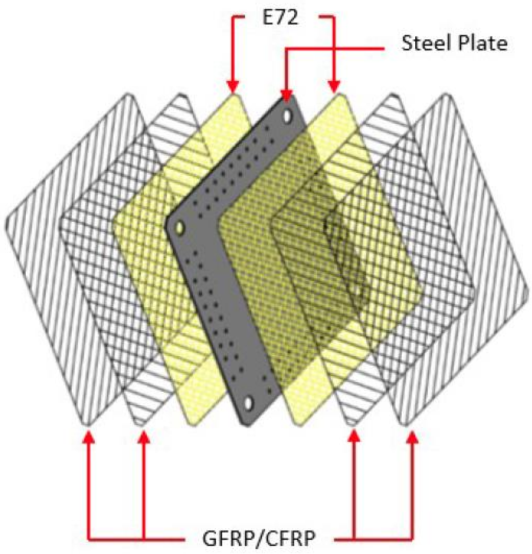


Figure 1. Arrangement of Sample 2 (Dakhel, 2017)

The characteristics of all samples are shown in Table 1 below where 'A' denotes adhesive film EF72 and 'S' denotes Steel plate.

Table 1: Arrangement of Hybrid Infill Plates

S. No	Specimen	Description	Stacking sequence of infill plate	Steel Plate Thickness	Size
1	4CSSW	CFRP without adhesive	(+45°/-45°/S/-45°/+45°)	0.8 mm	640 mm x 640 mm
2	4GSSWA	GFRP with adhesive	(+45°/-45°/A/S/A/-45°/+45°)	0.8 mm	640 mm x 640 mm
3	4GSSW	CFRP without adhesive	(+45°/-45°/ S/ -45°/+45°)	0.8 mm	640 mm x 640 mm

2.2 Testing Rig

For the testing, a special diamond shaped testing frame had been developed for holding the different infill plate samples as described earlier (Dakhel, 2017). The frame was manufactured with 4 pin joints as shown in the figure. The sections have 2 rows of 10 mm diameter holes which are spaced at 40 mm. In the frame, the number and positioning of the holes have been designed to minimize any risk for destruction of the plate at the point of connection while testing process. The design of the experiment is aimed at clarifying the behaviour in terms of buckling, ultimate load and the energy dissipation developed in different types of infill plates. The Gauges used during the project experiment were linear strain gauges and rosette gauges. These types of gauges have been applied at specific locations on the specimen as shown in Figure 2. The gauges are used to monitor the strain in different parts of the specimen during the testing process and recorded by data logger.

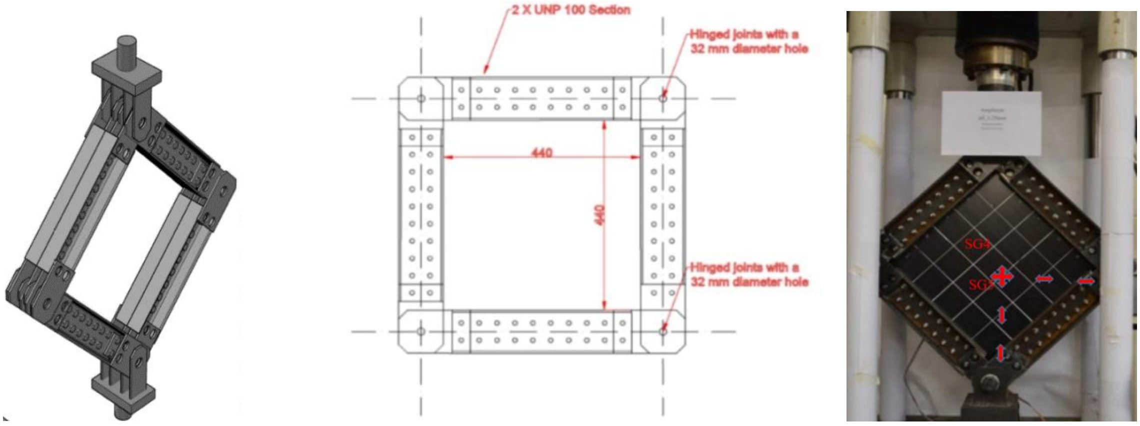


Figure 2. Testing Rig, frame and strain gauges on sample (Dakhel, 2017)

2.3 *Loading*

The loading protocol used in the experiment is the ATC-24 Protocol (Krawinkler, 1992). The ATC-24 is an American guideline adopted for cyclic seismic testing of components of steel structures, type of loading was specifically developed for steel structures for seismic performance evaluations of the components using a quasi-static loading. The loading pattern was displacement controlled with a gradual increase in the amplitude and can be illustrated in Figure 3. Initially, three cycles per amplitude were applied and later, above 20 mm amplitude displacement the cycle number was decreased further to two cycles per amplitude. Force is measured as part of the testing machine 'Mayes Universal Testing Machine 4 Column 300 kN with 20 Hz capacity'

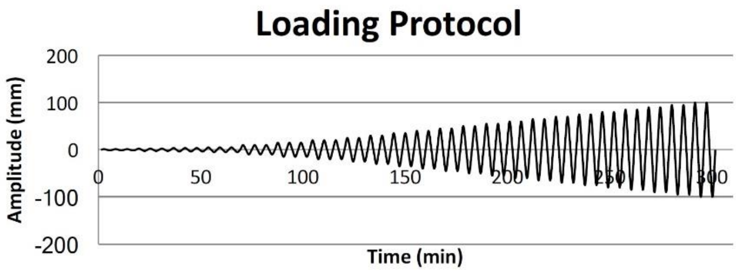


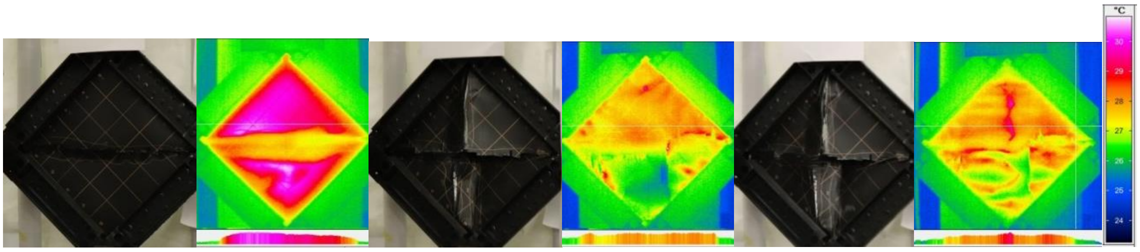
Figure 3. ATC 24 Loading Protocol (Dakhel, 2017)

2.4 *Infrared Investigation*

The Mode of failure during the experiment have been recorded using a high resolution VarioCAM infrared camera which helps to determine the areas of delamination, which is later processed and analysed using a Thermographic Software called IRBIS. In order to estimate the delamination areas between the FRP and steel, an external heat gun used to heat up the infill plate during cyclic loading intervals or the dwelling stage. The debonding of the steel and the FRP wrapping which occurs during the testing can be seen in the figures below. Several high-resolution photographs have been also recorded at peak loads of each cycle. The photographs can be compared with the infrared images to identify the delamination process which show clearer images of the delamination with identifying areas which are not visible on the photographic image. The extent of the delamination process can be clearly seen with the distribution of the temperature differences shown in different colour codes.

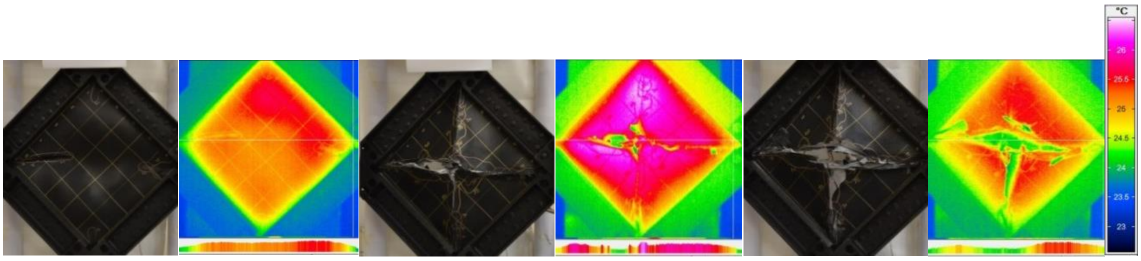
3 RESULTS AND ANALYSIS

3.1 Infrared images and delamination



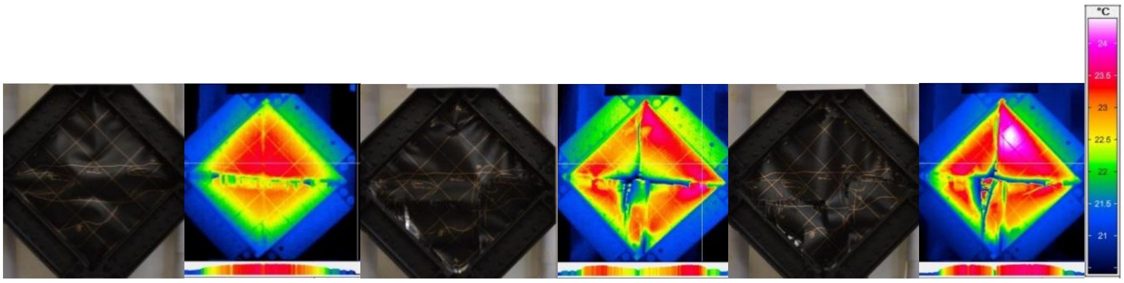
A B C

Figure 4. Gradual Damage and Thermal Images showing gradual delamination of Infill Plate of 4CSSW at 20 mm(A), 40 mm(B) and 60 mm(C) displacement



A B C

Figure 5. Gradual Damage and Thermal Images showing gradual delamination of Infill Plate of 4GSSWA at 20 mm(A), 40 mm(B) and 60 mm(C) displacement



A B C

Figure 6. Gradual Damage and Thermal Images showing gradual delamination of Infill Plate of 4GSSW at 20 mm(A), 40 mm(B) and 60 mm(C) displacement

In Figures 4-6, the gradual delamination of the steel and the CFRP/GFRP laminate occurred during the testing. It was also observed that there was a very good correspondence between the thermal images as shown in Figures 4-6 and the actual image of the specimens at different amplitudes. The thermal images evidently show the locations of the delamination areas as well as its extent using the distribution of the difference in temperatures. It is also noted that the area of delamination recoded from the thermal images show more precise picture of the delamination with identifying areas which are not visible on the photographic image.

3.2 *Hysteresis Curves*

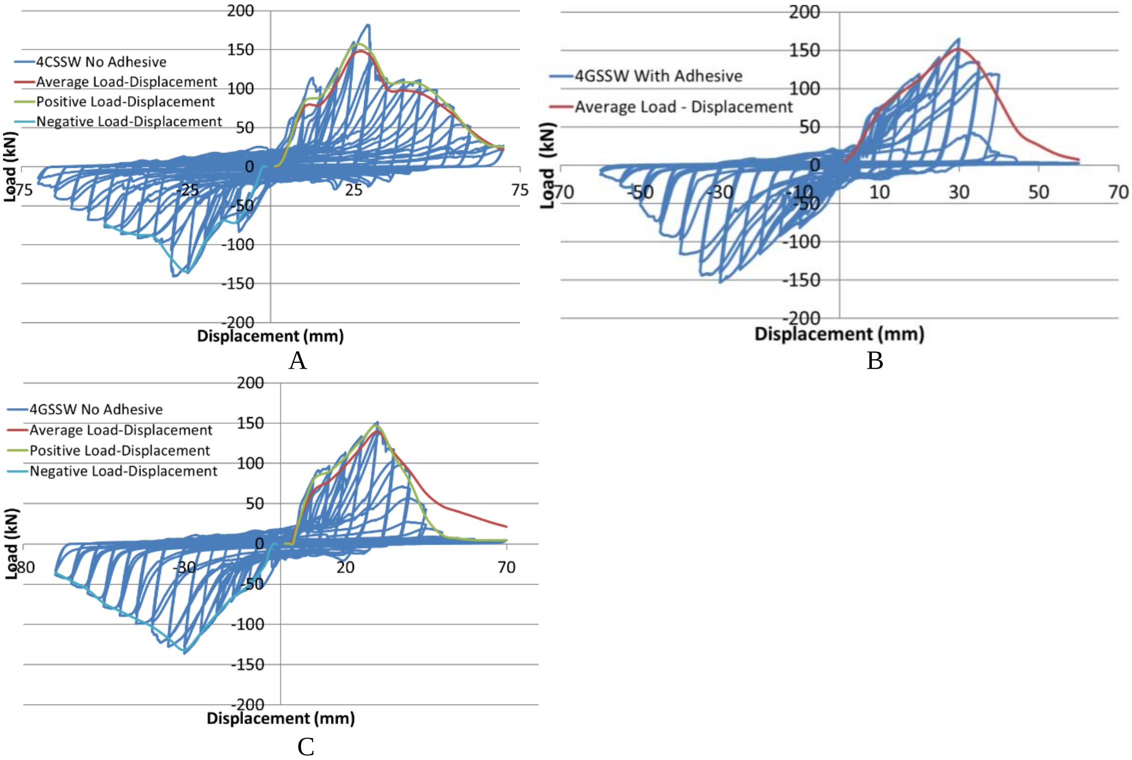


Figure 7. Hysteresis Curve for 4CSSW (A), 4GSSWA (B) and 4GSSW (C).

The Experiment had been terminated when the Average Load Capacity is 14.4 KN at 75 mm Displacement for 4CSSW, 7.47 KN at 60 mm for 4GSSWA and 20 KN at 70 mm for 4GSSW. It is noted that for all specimens, the negative values in the mid-part of the experiment are a bit swollen than the positive ones which may be due to the minor eccentricity in the testing rig.

3.3 *Load Displacement curves*

Following the loading as per the quasi static ATC 24 protocol, the load vs. displacement graphs for the samples tested were plotted in Figure 8 below.

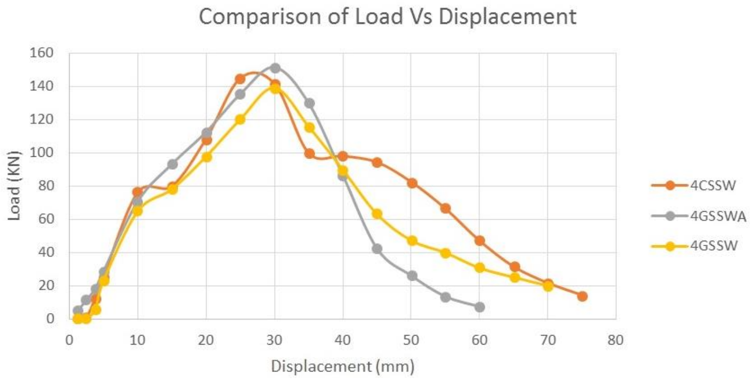


Figure 8. Comparison of the Load Vs. Displacement Graphs

Figure 8 illustrates the load vs. displacement graphs for the samples tested. The addition of the adhesive to 4GSSWA sample resulted in a minor increase to the Ultimate load capacity of 152 kN in comparison to the sampe without adhesive that is 4GSSW. The sample GSSW is showing the lowest Ultimate Load of 139 kN.

3.4 Cumulative Energy Dissipation

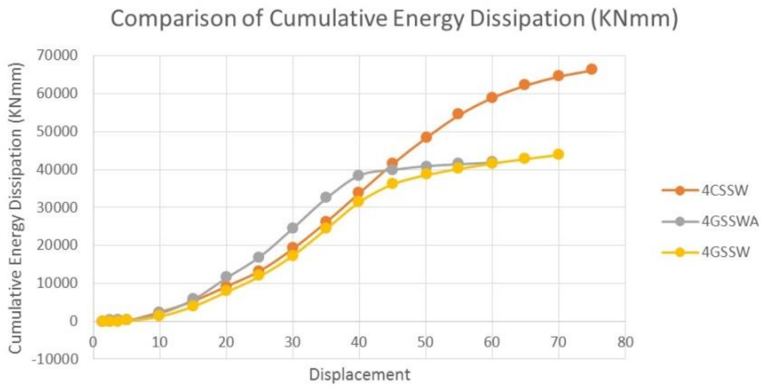


Figure 9. Comparison of Cumulative Energy Dissipation

In Figure 9, it can be seen that upon comparison of the cumulative energy dissipation, all the hybrid infill plate specimens exhibit similar pattern in the increase of cumulative energy dissipation up to a displacement of 40 mm. At about 50 mm displacement, the difference in the energy dissipation was significant between the samples with 4CSSW having higher energy dissipation than 4GSSSWA and 4GSSW. The cumulative energy dissipation for the 4CSSW continued to increase as the steel plate in the sample continued to yield until failure occurred at 75 mm as compared to 60 mm for 4GSSW and 70 mm for 4GSSWA. Failure has been defined as when the average load values after reaching its ultimate load capacity are re 20 KN or less.

The most significant increase of cumulative energy up to 43 mm displacement can be observed in 4GSSWA. Above 43 mm up to 75 mm displacement, the highest values of cumulative energy dissipation can be seen in 4CSSW. The 4GSSW sample presents a similar development in the energy dissipation like the 4CSSW sample up to 40 mm displacement but after 40 mm displacement the increase is at a slower pace.

4 CONCLUSION

The research was focussed on the energy dissipation and behaviour of the different combinations of hybrid infill plates for shear walls. Using the Infrared Thermography for the detection of delamination of FRP and assessing the effect of the additional adhesive layer between the laminate and the steel plate are between the main factors investigated. The variable was the use of Glass and Carbon FRP and usage of adhesive layer.

Further to the research experiment, the following conclusions can be drawn:

1. Ultimate load for all hybrid samples is not varying significantly. It is within the limits of 139 KN to 152 KN.
2. The Ultimate Strength of sample with adhesive is a bit higher than for the samples without adhesive.
3. Cumulative Energy Dissipation is varying significantly. Up to 40 mm displacement, the highest value is for 4GSSWA and above it, up to 70 mm displacement highest value for Cumulative Energy Dissipation is for 4CSSW.
4. Infrared Thermography is used successfully for estimating the delaminated areas at different levels of loading.
5. Obtained results are allowing for detecting areas of delamination which are not visible from naked eye observation

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