



Citation for published version:

Grammatikos, S, Kordatos, EZ, Matikas , TE & Paipetis, AS 2015, Service and maintenance damage assessment of composite structures using various modes of infrared thermography. in *Advanced Materials for Demanding Applications.*, 012006, IOP Conference Series : Materials Science and Engineering, vol. 74, IOP Publishing. <https://doi.org/10.1088/1757-899X/74/1/012006>

DOI:

[10.1088/1757-899X/74/1/012006](https://doi.org/10.1088/1757-899X/74/1/012006)

Publication date:

2015

Document Version

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2015 IOP Conf. Ser.: Mater. Sci. Eng. 74 012006

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Service and maintenance damage assessment of composite structures using various modes of infrared thermography

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Abstract. Carbon Fibre Reinforced Polymers (CFRPs) have been widely used recently in aerospace technology as primary materials. During aircraft operation the combination of thermo-mechanical loads, gradually degrades the material properties. Therefore, the development of reliable and cost effective damage inspection protocols throughout the service life of these structures is of primary importance for their safe function. Within the scope of this study, Infrared Thermography (IrT) was employed with the aim of assessing the structural integrity of composite aero-structures in both maintenance (off-line) and service (on-line) conditions. In the maintenance concept, IrT was employed in Lock-in mode to evaluate artificially induced damage in bonded repaired materials. For this purpose, various configurations of damage were investigated. In the service concept, IrT was employed for the continuous monitoring of loaded repaired structures in order to assess in real-time any progressive evolution of de-bonding which could lead to failure of the bonded patch repair. The experimental results provided evidence that IrT is capable of qualitative and quantitative field assessment of aero-structures.

1. Introduction

Fibrous reinforced composites are being widely used the last decades in various applications in aerospace. Back to the 19th century the first composite materials were developed by wood and natural resins. Nowadays, composites are used more and more as materials for primary structures in demanding applications. The Boeing 787 Dreamliner and the Airbus A350 XWB are examples of extensive use of Carbon Fibre Reinforced Polymers (CFRPs) and Glass Fibre Reinforced Polymers (GFRPs). With respect to aircraft maintenance, the replacement of a structurally degraded part is not always desirable due to the increased cost. Therefore, efficient repair technologies are always in demand for qualification as standard practices in the aircraft industry. Bonded composite repair is a relatively new repair concept primarily proposed by Baker in Australia [1], which proposes the use of composite materials directly bonded onto the cracked surface. Bonded composite repairs offer significant advantages over the conventional mechanical fastened repair methodologies [2]. At the same time, the development of new materials in high performance applications requires effective methodologies for structural integrity assessment during service, operation and maintenance. Non-



Destructive Evaluation (NDE) techniques allow for the assessment of the internal structural state, i.e. defects, anomalies, critical and subcritical damage incidents. A variety of NDE techniques are employed in the aircraft industry. Ultrasonics [3], radiography [3], thermography [4] and Lamb wave [5] methods are the NDE techniques commonly employed in aero-structures when high detection resolution and accuracy is needed. Infrared thermography (IrT) is a full-field and non-contact structural integrity methodology which exploits the infrared thermal radiation emanated by the investigated material surface. IrT is applied using two fundamental modes which refer to the type of excitation, *i.e.* active and passive. In passive mode, no external thermal source is required whereas in active mode, thermal excitation is achieved via an external stimulus. Various stimulation methodologies have been proposed [2]. Optical (lamps) [6], ultrasound [7], eddy current [8], cyclic loading [9] and current injection [4] are the most frequently used types of thermal stimulation. With respect to maintenance, IrT can be easily employed to detect induced damage. In typical composite structures damage is manifested as delaminations, voids, de-bonding etc. While in service, IrT is capable of recording the initiation and propagation of any induced damage in real time. In the case of periodic loading, the mechanical loading waveform is often synchronized with the thermal sensor acquisition frequency. This system allows for the monitoring of the generated internal stresses which ultimately lead to failure.

In this work, IrT was employed to assess damage both in maintenance (off-line) and service (real time) modes. With respect to maintenance, CFRP patches were applied to repair both composite and Aluminum (Al) substrates. In both substrate scenarios, PTFE tapes were introduced in various locations of the repaired structure to simulate delamination, de-bonding as well as poor bonding. Teflon tapes of constant thickness, but various geometries were situated in-between the layers of the repair and in the patch /substrate interface. The repaired coupons were examined with optical IrT. More specifically, optical Lock-in thermography (LT) was adopted to pin-point the damage concepts. In optical LT, the thermal sensor is continuously synchronized with the source of heating, which in this case is an array of optical lamps. With regards to service, an artificially cracked aluminum helicopter wing (the stabilizer of the SW-4, PZL-Swidnik /AgustaWestland) was repaired using a CFRP bonded patch. In this concept, LT was employed on-line during cyclic mechanical loading to monitor the durability and efficiency of the patch repair. In all stages, IrT was capable of detecting artificially induced damage and monitoring damage evolution in real conditions

2. Experimental

2.1. Maintenance assessment; bonded composite repaired Al and composite substrates

Al and composite plates were repaired with CFRP patches. These consisted of, (i) 6 aluminum substrate coupons, and (ii) 6 composite substrate coupons repaired with 5-ply CFRP patches. For the patch manufacturing, a satin weave fabric provided by (5H SATIN 43280) HEXCEL was employed for patch reinforcement and Epocast 52 A/B for the patch matrix. The orientation of the patch reinforcement was $[0/90^\circ/0/90^\circ/0]$. The thickness of the Al substrates was 1.6mm. Regarding the composite substrate case, the reinforcement was provided by a pre-preg (MTM®56-cure cycle: 30 min at 120 °C) woven carbon fabric (199 g/m²) by ACG (UK). The thickness was approximately 1.6mm (identical to the Al case).

2.2. Service assessment; bonded composite repair of al helicopter wing

The structure of the stabilizer consisted of an internal core HexWeb CR III-3,8 5/32-10 (5052). The honeycomb thickness diverges from 32mm to 34.2mm. The aluminum skin was manufactured by the 2024 T3 alloy sheet. The thickness of the external surface varied from 0.4mm to 1.5mm. Figure 1 depicts the prepared for test stabilizer as well as a scheme with the dimensions of the wing structure.

After previous analysis and dynamic testing on the stabilizer, a crack was noticed that has started in the vicinity of the one of four adjusting (on the fuselage) bolted joints. To that respect, this area was repaired with a CFRP patch.

In Figure 1b and 1c one can distinguish the applied bonded composite patch. The artificial crack is shown in Figure 1a. As can be seen, the crack was created close to the bolted joint. Figure 1d displays a schematic representation of the wing. For the requirements of the composite patch, the Hexcel 43280s series carbon fabric was adopted. As for the matrix, the Epocast 52 A/B was utilized.

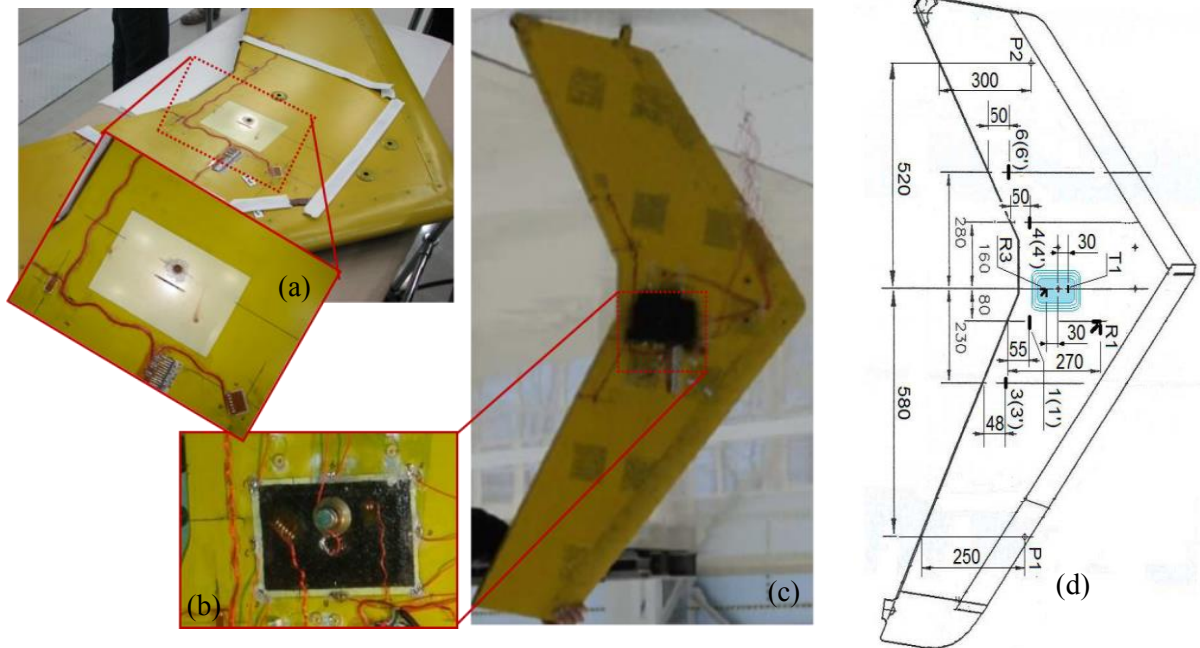


Figure 1. (a) Artificial crack (35mm), patched region, (b) applied bonded patch ($80 \times 120 \text{mm}^2$), (c) SW 4 helicopter vertical stabilizer, (d) schematic representation of the stabilizer.

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3. Results and discussion

3.1. Maintenance assessment

Figures 2a (i-iii) and 2b (iv-vi) depict the thermographic images derived when scanning the repaired plates with LT. Grey and yellow coloured shapes on the coupon configuration schematics represent the location and shape of the artificially induced damages. The thermographic experimental parameters are listed in Table 1.

Table 1. Experimental parameters of thermographic evaluation.

Method	Lock-in Thermography					
Configuration	<i>i</i>	<i>ii</i>	<i>iii</i>	<i>iv</i>	<i>v</i>	<i>vi</i>
Frequency /Hz	0.01	0.1	0.01	0.05	0.05	0.01
Voltage /V	3	2	3	2	2	3
Distance /m	1.18	1.18	1.18	1.18	1.18	1.18
Periods	2	5	2	3	4	2

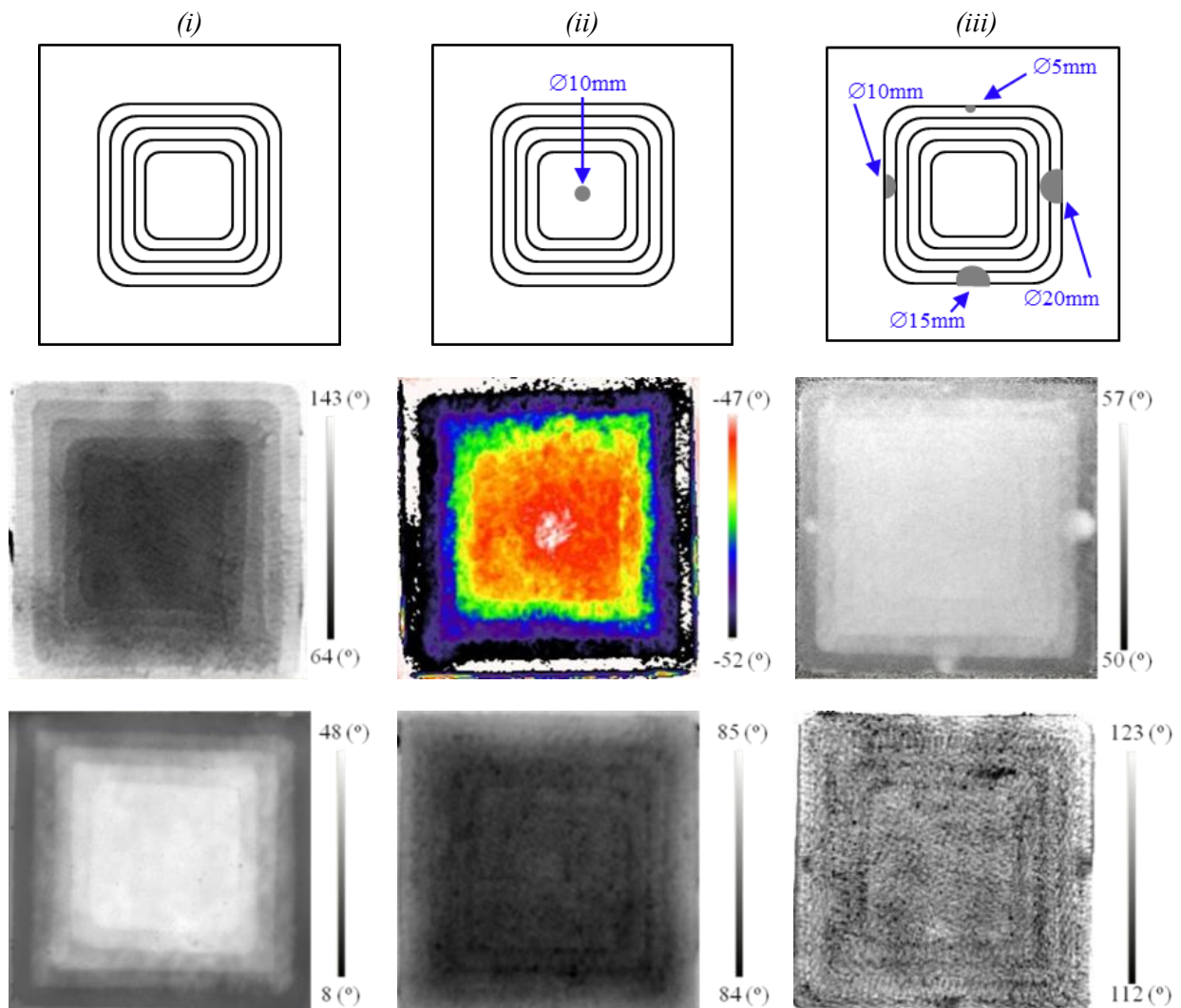


Figure 2a. (A) Coupon configuration, (B) Phase images by lock-in thermography; Al substrate, (C) Phase images by lock-in thermography; Composite substrate, (i) No defect, (ii) Central patch substrate de-bonding, (iii) Patch substrate de-bonding.

As is obvious from Figures 2a and 2b, all interrogated artificial defects were detected. In Figure 2a (i) the undamaged reference specimen is depicted. Figure 2a (ii) shows the inserted teflon defect in the centre of the repaired plate. In the case of Al substrate, damage is easier witnessed when using the colorful palette. In Figure 2a (iii) all artificial PTFE flakes between the patch and the mother structure are visible. In Figure 2b (iv) the induced damage between the layers of the patch can be readily discerned. A surface defect visible to naked eye is also identified. In Figure 2b (v) the triangular Teflon insert is easily unscrambled. Figure 2b (vi) depicts the 50% simulated bad adhesion. In this damage configuration thermography was not as successful as for the rest. For this damage concept, oil grease was employed to provoke “bad” adhesion. The thermographs indicate that “bad” adhesion was not traceable. On the contrary it is possible that the majority of the patch/substrate interface remained intact. Poor adhesion is manifested as fade bright areas in the middle of both repaired substrates. In all phase images above the different layers of the patch are visible. Moreover, high consolidation

degree of the manufactured patches was observed. It is noteworthy that the thickness of the Teflon defects was equal to 50 μm , lower than in other studies [6]. Although their detection was feasible, reduced thickness additionally hampered the discerning efficiency of the artificial defects.

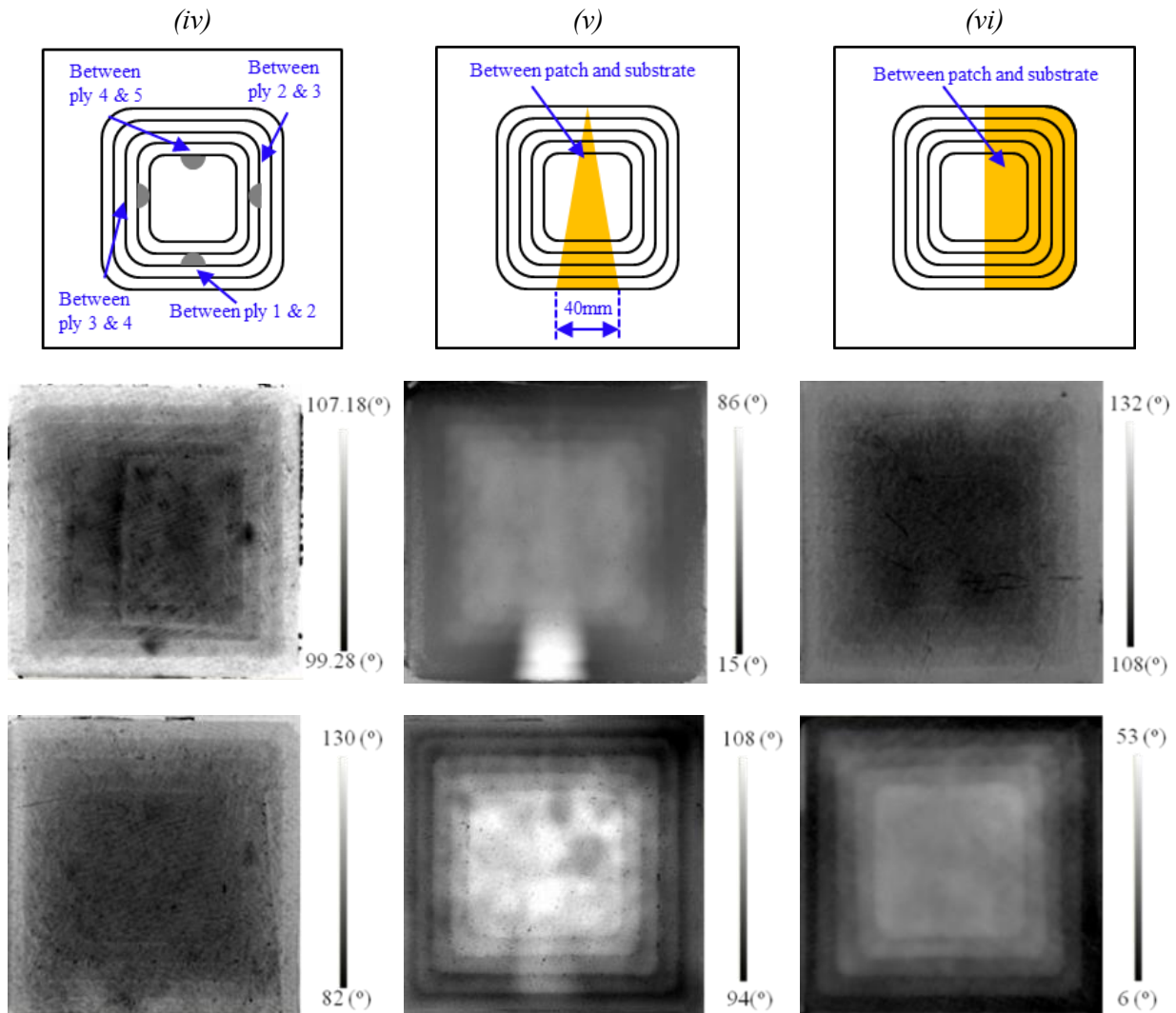


Figure 2b. (A) Coupon configuration, (B) Phase images by lock-in thermography; Al substrate, (C) Phase images by lock-in thermography; Composite substrate, (iv) Delamination between patch layers, (v) Triangle de-bonding, (vi) 50% bad adhesion.

3.2. Service assessment; bonded composite repair of Al helicopter wing

In Figure 3 the testing configuration is depicted. The induced bending moments were in different amplitude in order to equilibrate the distance difference between the centre and the clamped points. The structure was tested in 20Hz cyclic bending fatigue. The infrared camera was synchronized with the frequency of the testing machine providing both amplitude and phase images. The infrared sensor was appropriately positioned vertically-faced above the repaired side of the stabilizer (Figure 3). The distance between the camera and the stabilizer was approximately 0.8m. Having two signal outputs from the controller, the camera was connected with the P1 loading moment. The frame rate of the infrared camera was set to capture four images per loading cycle.

The sequence of amplitude images in Figure 4, were observed with lock-in thermography during representative loading cycles. Amplitude images represent the recorded temperature difference on the structure. The deterioration of the patch is reflected by the color change on the particular images.

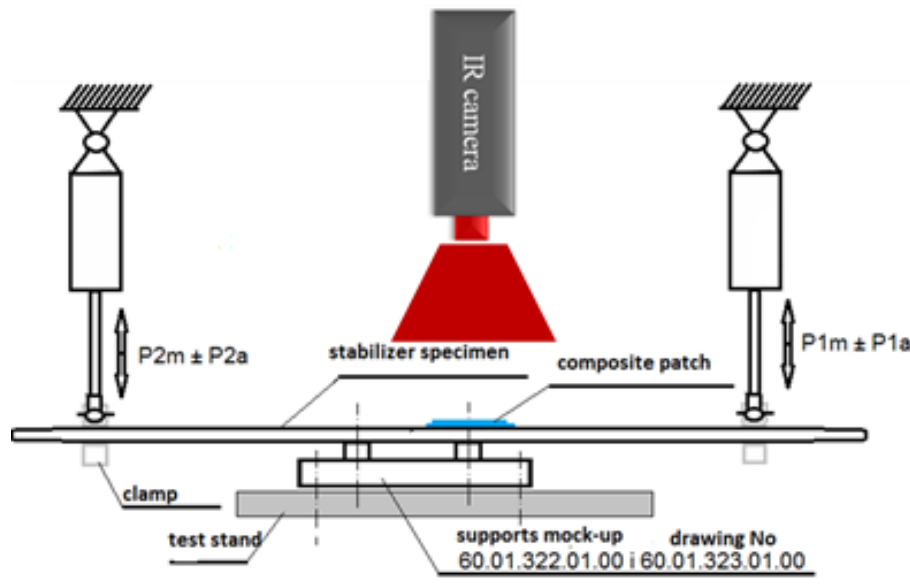


Figure 3. Experimental setup.

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4. Conclusions

Within the context of this study, IrT was applied in both maintenance (off-line) and service (online) modes to assess structural integrity of bonded composite repaired structures. Initially, thermography was used to interrogate artificially induced damage simulated by Teflon. Both Al and composite substrates were repaired and subsequently inspected off-line. In a second stage, thermography was employed in real time to monitor initiation and propagation of damage in a repaired helicopter vertical stabiliser.

With regard to off-line investigation, good detection efficiency was achieved for most damage configurations employed in the study. Teflon tapes were identified with higher accuracy than “bad adhesion, induced by oil grease. It is worth mentioning that the applied oil grease is barely visible. This implies that might was inadequate in causing ‘bad adhesion’, allowing for smooth heat transfer between the patch and the substrate. Detection of defects was less demanding in the case of Al substrate due to the difference in the coefficient of thermal expansion. In the case of composite repaired substrates, higher consolidation between composite-composite as well as the identical coefficient of thermal expansion hindered the detection process. In all cases, Teflon inserts entrapped heat due to their lower thermal conductivity compared to the rest of the structure. Therefore, Teflon was discernible when scanned with a thermal sensor.

In the case of real-time damage assessment, IrT proved a powerful tool for damage initiation and propagation monitoring. The application of load was visualised as different colour contours on the surface of the patch. Mechanical loading generated stresses internally which led to the detachment of the patch from the Al substrate. Changes in colour mirrored the differentiation of the stress gradient along the repaired area. Generated stresses were the result of thermomechanical coupling. Thermographic images reflected the debonding process of the patch from the substrate. Debonding

initiated mainly from the loci of the bolted joint where apparently the mechanical stresses were maximum. Stress concentrations moved along the repaired area as the patch detached from the substrate. The artificial crack was initially visible, however, after prolonged testing, the loss of patch /substrate interface covered the thermal trace of the crack. This effect was a secondary proof that IrT was capable of capturing critical damage in real time, which in this study was manifested as patch debonding.

In summary, IrT was successful in detecting damage both in maintenance and service conditions in bonded composite repaired materials and structures.

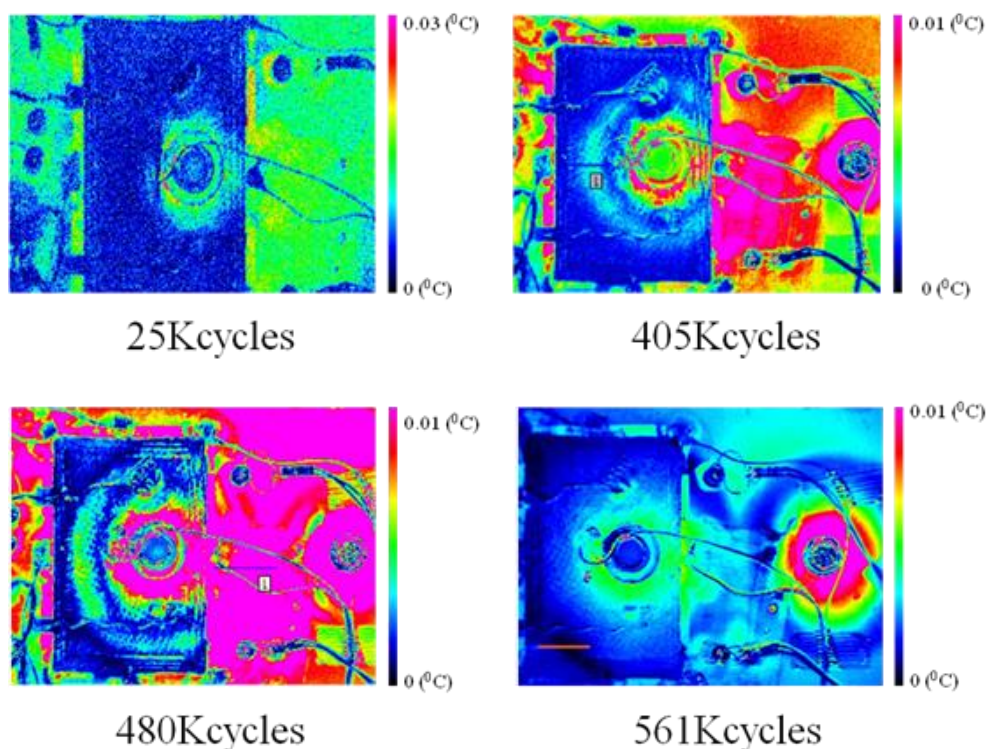


Figure 4. Amplitude images obtained from lock-in thermography at representative loading cycles.

References

- [1] Baker AA, 1984, *Composite Structures*, **2** 153-81.
- [2] Grammatikos SA, 2013, *Dept. Materials Science Eng.*, University of Ioannina, Greece, 286.
- [3] Jasinien E, Raiutis R, literis R, Voleiis A, Vladiauskas A, Mitchard D, Amos M, 2009, *Insight - Non-Destructive Testing and Condition Monitoring*, **51** 477-83.
- [4] Grammatikos SA, Kordatos EZ, Matikas TE, David C, Paipetis AS, 2014, *Materials & Design*, **55** 429-41.
- [5] Kundu T, Maslov K, Karpur P, Matikas TE, Nicolaou PD, 1996, *Ultrasonics*, **34** 43-9.
- [6] Grammatikos SA, Kordatos EZ, Barkoula NM, Matikas TE, Paipetis AS, 2011, *Plastics, Rubber and Composites*, **40** 342-8.
- [7] Zweschper T, Dillenz A, Riegert G, Scherling D, Busse G, 2003, *Insight: Non-Destructive Testing and Condition Monitoring*, **45** 178-82.
- [8] Pan M, He Y, Tian G, Chen D, Luo F, 2012, *NDT & E International*, **52** 28-36.
- [9] Grammatikos SA, Kordatos EZ, Matikas TE, Paipetis AS, 2013, *J. of Materi Eng and Perform*, **23** 169-80.