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Shearography non-destructive inspection for space applications

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ABSTRACT

In this work, we explore the feasibility of shearography non-destructive inspection for space structures like the International Space Station. We aim at pushing this technique towards passive inspection to eliminate the power-demanding excitation by leveraging natural excitations as orbital sunrises. A concept prototype will be developed for ground laboratory tests, specifically tailored for space applications. This is the first step towards our long-term goal of developing a shearography instrument capable of autonomously inspecting space structures, integrated into a robotic manipulator alongside other NDI solutions, such as thermography. The value of shearography is in the mechanically interpretable results that can support predictive assessments like residual life estimation. This research is performed as part of the ESA OSIP ShearScope project (No. 4000148089).

Keywords: Shearography, non-destructive inspection, large space structures, on-orbit inspection, passive excitation

1. INTRODUCTION

Current on-orbit inspections of structures rely heavily on visual or video checks, which reveal only major visible issues [1]. For large structures in longer missions, risks from micrometeoroids, orbital debris, and failed joints increase, and common problems like cracks and disbonds remain.

After the Columbia incident, non-destructive inspection (NDI) received a significant boost [2,3]. Space structures are inspected during manufacturing on the ground, while on-orbit NDI lags behind. NDI engineers have handbooks with extensively evaluated NDI techniques, where shearography (a full-field speckle pattern shearing interferometry) is shortlisted for its non-contact, high-productive inspection [4–6]. Shearography directly assesses microstrain-level surface irregularities using external excitation, e.g. heat or vibration, which is captured with cameras in laser light. This high strain sensitivity enables the detection of small but critical defects like closed cracks and kissing bonds, that often remain hidden.

In this work, the feasibility of a (FEM-assisted) shearography non-destructive inspection [7–10] for space structures, such as the International Space Station, is explored. The aim is to push this technique towards passive inspection to eliminate the power-demanding excitation by leveraging natural excitations as orbital sunrises. A concept prototype will be developed for ground laboratory tests, specifically tailored for space applications. The goal is to push the application boundaries of shearography to enable detection of submillimeter or deep defects [11], inspection of curved objects [12] – developments often beyond the scope of commercial instrumentation. This work can contribute to reliable and energy-efficient on-orbit inspection.

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2. SPECIMEN DESCRIPTION AND EXPERIMENTAL SYSTEM

2.1 Specimen description

Several space-related composite components are inspected with shearography instrument (TU Delft). The specimens include an aluminum-cork specimen and a carbon-carbon plate, which are commonly used for re-entry space shuttles [13–16].

- The aluminum-cork specimen is around 300 × 210 × 4.5 mm with a simulated "A"-shaped defect (Figure 1(a)). To improve the inspection efficiency, the specimens were painted with white matte paint. The inspection was made from the cork side with the front heating, as it is the outer surface of the structure.
- The carbon-carbon plate is around 115 × 115 × 2.2 mm with potential debond defect (Figure 1(b)). No surface treatment was required before the inspection.

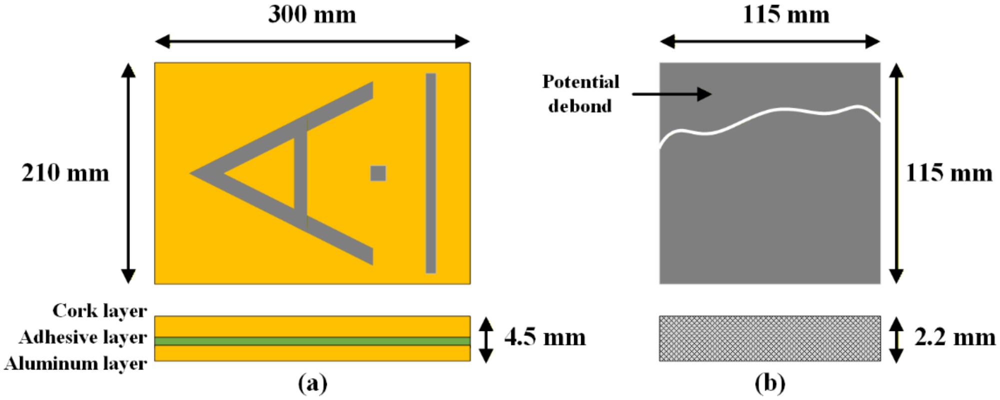

Figure 1 Diagram of (a) aluminum-cork specimen with a simulated 'A'-shape defect and (b) C-C specimen with potential debond.

2.2 Experimental shearography system

Shearography (speckle pattern shearing interferometry) is an optical full-field speckle interferometry technique with high sensitivity to the surface displacement gradient when the object is deformed. Shearography theory and the principle of its operation are well described in the literature [4–6]. For this inspection, one channel of the previously developed and reported 3D shape shearography instrument [12,17] was used (Figure 2) together with thermal loading (heating) of the specimen. The choice of one shearing camera oriented perpendicular to the specimen with the main sensitivity to the out-of-plane surface displacement gradient was made based on the preliminary information about the defect type (delamination).

During the tests, the specimens were inspected one after another, with three halogen lamps operating at maximum power (electrical power of 1 kW each) to simulate solar heating in orbit. The distance between the specimen and the lamps was approximately 50 cm to achieve temperature changes similar to those fluctuations during orbital sunrise. During natural cooling, the specimens were continuously monitored with the shearography camera.

All the images in this report represent deformations of the specimens after the replicated orbital solar heating, as measured using the shearography instrument.

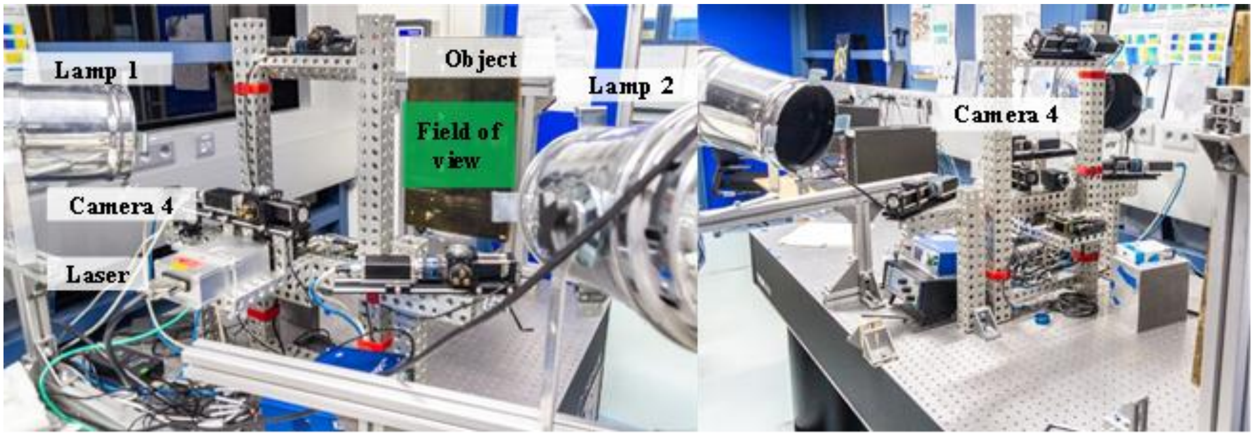

Figure 2 Overview of the 3D shape shearography instrument. The specimen is used for demonstration.

3. RESULTS AND DISCUSSION

The passive excitation of orbital solar heating is replicated in the laboratory environment using three halogen lamps, each with nominal electrical power of 1 kW (Figure 2). As the material behavior during orbital sunrises is well documented in [15,16,18], we used these findings in literature as references for reliable construction of the orbital solar heating profile.

The thermal responses of the specimens subjected to replicated orbital solar heating are presented in Figure 3(a). Results from literature [15,16] are shown in Figure 3(b) for comparison. The maximum temperature change achieved in the lab is around 88 °C, which is comparable to the values in space (80-120 °C) for the reinforced carbon–carbon (RCC) structures of the Shuttle at Low Earth Orbit. It is good to note that the sunrise phase of an orbital cycle in space lasts 45 minutes. In the laboratory, 20 minutes of heating was applied, as this achieves a temperature close to the equivalent.

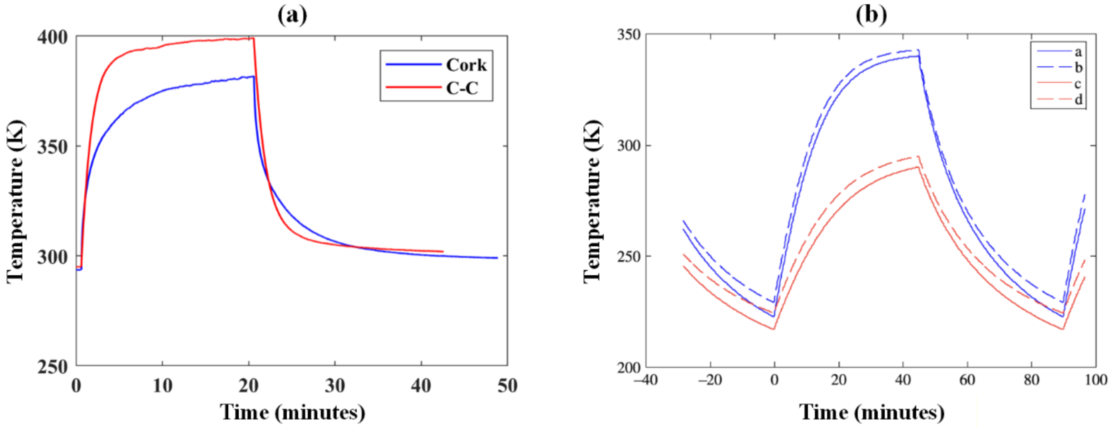

Figure 3 Results of thermal response of the specimens under the replicated orbital solar heating: (a) the aluminum-cork plate with ‘A’ defects and the C-C plate with potential debond defect; (b) results from literature [15,16] as reference.

The inspection result of the aluminum-cork specimen under replicated solar heating is shown in Figure 4(a). The “A” shape defect in the specimen was revealed (indicated by red arrows) in the *y*-shear direction. The horizontal features did not appear due to the shear direction. The inspection result of C-C plate (*y*-shear direction) is shown in Figure 4(b) (with *y*-shear direction. Potential delamination in the plate was revealed (marked in red dotted area) under replicated solar heating.

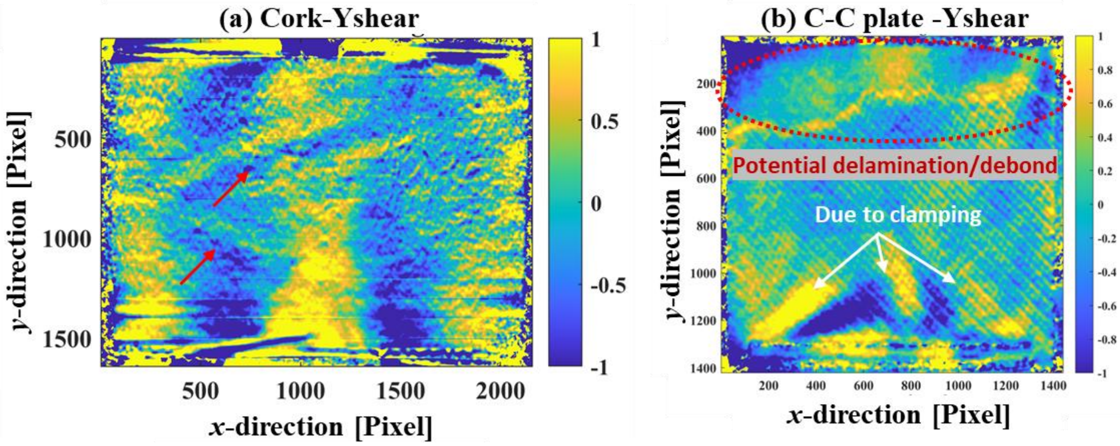

Figure 4 Shearography inspection results of (a) the aluminum-cork specimen and (b) the C-C plate under replicated orbital solar heating.

4. CONCLUSIONS

Inspection of the aluminum-cork specimen and the carbon-carbon plate was conducted under replicated orbital solar heating. The *y*-shear direction was used during the inspection. The results show that utilizing orbital solar heating for shearography NDT of space structures is promising. Replicated orbital solar heating was achieved in a laboratory environment using available halogen lamps and a power modulation unit. The maximum temperature change was comparable to reference results in space. This work is the first step towards our long-term goal of developing a shearography instrument capable of autonomously inspecting space structures, integrated into a robotic manipulator alongside other NDI solutions, such as thermography. In the future, material behavior during passive excitation will be explored with FEM to support the experimental testing [7–10].

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REFERENCES

[1] Hyde JL, Christiansen EL, Lear DM. Observations of MMOD Impact Damage to the ISS. First International Orbital Debris Conference, 2009.

[2] Howell PA. Non-Destructive Evaluation (NDE) Methods and Capabilities Handbook. Langley Research Center, Hampton, Virginia: 2020.

[3] Lanigan EL, McDougal MR. Overview of Non-Destructive Evaluation Capabilities at NASA MSFC 2022.

[4] Steinchen Wolfgang, Yang Lianxiang. Digital shearography : theory and application of digital Speckle pattern shearing interferometry. SPIE Press; 2003.

[5] Yang L, Xie X. Digital Shearography: New Developments and Applications. SPIE; 2016. https://doi.org/10.1117/3.2235244.

[6] Francis D, Tatam RP, Groves RM. Shearography technology and applications: a review. Meas Sci Technol 2010;21:102001. https://doi.org/10.1088/0957-0233/21/10/102001.

[7] Tao N, Anisimov AG, Groves RM. Shearography non-destructive testing of thick GFRP laminates: Numerical and experimental study on defect detection with thermal loading. Compos Struct 2022;282:115008. https://doi.org/10.1016/j.compstruct.2021.115008.

[8] Tao N, Anisimov AG, Groves RM. FEM-assisted shearography with spatially modulated heating for non-destructive testing of thick composites with deep defects. Compos Struct 2022;297:115980. https://doi.org/10.1016/j.compstruct.2022.115980.

[9] Tao N, Anisimov A, Elenbaas M, Groves RM. Shearography non-destructive testing of a composite ship hull section subjected to multiple impacts. Proceedings of the 20th European Conference on Composite Materials: Composites Meet Sustainability, 2022.

[10] Tao N, Anisimov AG, Groves RM. Towards safe shearography inspection of thick composites with controlled surface temperature heating. NDT & E International 2023;139:102907. https://doi.org/10.1016/j.ndteint.2023.102907.

[11] Tao N, Groves RM, Anisimov AG. Shearography pair method for reliable non-destructive inspection of millimeter and submillimeter defects in fiber-reinforced composites. Measurement 2025;255:117980. https://doi.org/10.1016/j.measurement.2025.117980.

[12] Anisimov AG, Serikova MG, Groves RM. 3D shape shearography technique for surface strain measurement of free-form objects. Appl Opt 2019;58:498. https://doi.org/10.1364/AO.58.000498.

[13] Drescher O, Hörschgen-Eggers M, Pinaud G, Podeur M. Cork Based Thermal Protection System for Sounding Rocket Applications – Development and Flight Testing. Proceedings of the 23rd ESA PAC Symposium, Barcelona, Spain: 2017.

[14] Lingbloom M. Comparisons of NDT Methods to Inspect Cork and Cork-Filled Epoxy Bands. ASNT Fall Conference, Las Vegas, NV, USA: 2007.

[15] Howell PA, Winfree WP, Cramer KE. On-orbit passive thermography. Nondestructive Testing and Evaluation 2008;23:195–210. https://doi.org/10.1080/10589750701855171.

[16] Howell PA, Winfree WP, Cramer KE. Infrared on-orbit inspection of shuttle orbiter reinforced carbon-carbon using solar heating. In: Hanssen LM, Farrell P V., editors., 2005, p. 588009. https://doi.org/10.1117/12.615332.

[17] Anisimov AG, Müller B, Sinke J, Groves RM. Analysis of thermal strains and stresses in heated fibre metal laminates. Strain 2018;54:e12260. https://doi.org/https://doi.org/10.1111/str.12260.

[18] González Bárcena D. Planetary and low orbit thermal environment for space thermal design. Universidad Politécnica de Madrid, 2022. https://doi.org/10.20868/UPM.thesis.72025.