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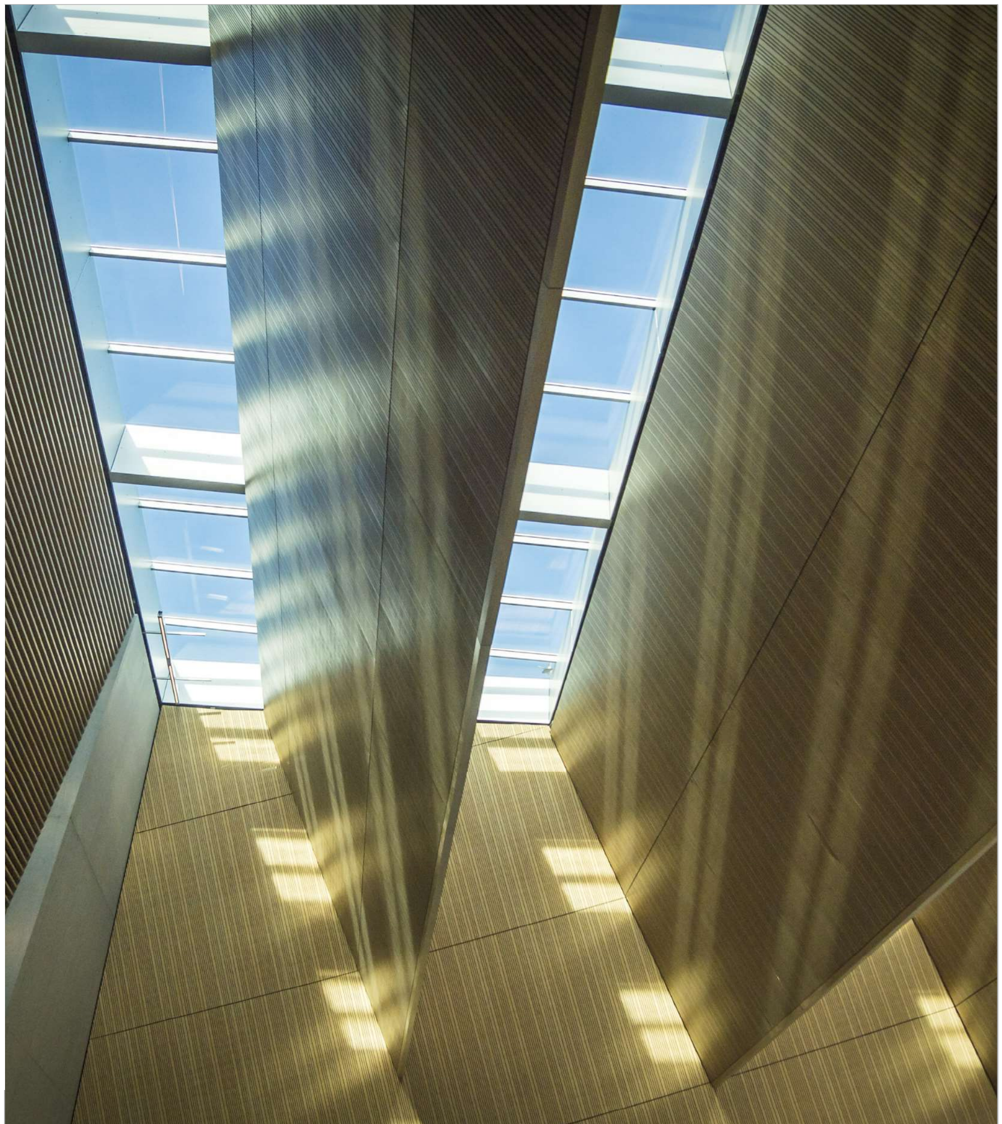

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Vol 3 – Characterization

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SHEAROGRAPHY NON-DESTRUCTIVE TESTING OF A COMPOSITE SHIP HULL SECTION SUBJECTED TO MULTIPLE IMPACTS

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Abstract: *The use of thick composites and sandwich structures is increasing rapidly in diverse industries. Nevertheless, due to extreme loads such as impact and blast, various defects tend to occur in thick composites that can degrade the structural integrity severely. Hence, it is important to advance non-destructive testing (NDT) towards composite structures of significant thickness. The objective of this study is to perform shearography NDT of a composite ship hull section which has been multiple impacts in the RAMSSES project. In this paper, experimental results on the inspection of the large-scale composite structure are reported. Different loading scenarios including step heating and mechanical loading were performed for shearography NDT. A comparison between thermal loading and mechanical loading on thick composite inspection with shearography is presented. Here we aim at bringing the shearography technique out of the laboratory and extending its applications to composites with a thickness of more than 50 mm.*

Keywords: thick composite inspection; shearography NDT; composite ship hull section; multiple impacts; thermal and mechanical loading

1. Introduction

Owing to the remarkable advantages of lightweight and superior material properties, composite materials are seeing widespread applications in various industrial sectors [1–4]. Initially, these materials were mainly used in thin structures, but in recent years the use of thick composites and sandwich structures has increased rapidly in the marine sector (e.g. decks and hulls) [1] and in wind energy (e.g. wind turbine blades) [3,4]. Particularly, sandwich structures consisting of glass-fiber laminate skins bonded to a foam core are attractive in the marine sector due to their resistance to corrosion and underwater shocks and cost-effectiveness [5]. Those marine composites tend to have significant thicknesses (e.g. 50-200 mm) and to be large-scale (e.g. up to 85 m in length). Nevertheless, they are susceptible to extreme loads such as impacts or blasts that can result in various defects including delaminations, core debonding, and fiber breakage. The presence of those defects can degrade material properties and structural integrity severely. Hence, it is important to advance non-destructive testing (NDT) towards composite structures of significant thickness.

Some well-known NDT techniques, including ultrasonic testing and thermography, are difficult to be implemented for thick composite inspection. For ultrasonic testing, the problems of attenuation [3,4] and practical coupling issues with high surface roughness are significant. For thermography, it is difficult to heat evenly a large structure and to avoid rapid heat dissipation in thick composites [3,4]. Among the various NDT methods, shearography [6,7] is an optical NDT method that offers many advantages such as full-field and non-contact measurement. It reveals defects by comparing two states of deformation of a test object. By applying a suitable loading, the defects can be revealed by looking for defect-induced anomalies in fringe maps or phase maps that can be related to surface strain components. It is possible to improve the sensitivity of shearography for defect detection by selecting suitable loading methods [8]. In shearography NDT, thermal loading is commonly used because of the advantages of versatility, non-contact, and low cost. Nevertheless, studies on the efficacy of mechanical loading on defect detection are rarely reported [9]. Our previous work with a 51 mm thick marine laminate [10] showed that defects at 5 to 20 mm depth can be detected successfully using shearography with thermal loading. Here we aim at bringing this technique out of the laboratory and extending shearography applications to large-scale composites with a thickness of more than 50 mm.

The objective of this study is to perform shearography NDT of a large-scale thick composite structure, specifically a composite ship hull section which had been subjected to multiple impacts. Different loading scenarios including step heating as well as mechanical loading were performed for shearography NDT. Section 2 describes the tested composite hull section and the shearography inspection system. Section 3 presents experimental inspection results of the large-scale composite structure. A comparison between thermal loading and mechanical loading on thick composite inspection with shearography is given in section 3 as well. The conclusions are given in section 4.

2. Shearography inspection system for the composite ship hull section

An overview of the composite ship hull section is shown in Fig. 1. The dimensions are about 6 meters in height and 2.3 meters in width. The structure is made from FRP laminate skins and foam cores. The composite ship hull section is a RAMSSES demonstrator [11,12] at Damen Shipyards. Before shearography inspection, multiple impact tests (https://vimeo.com/522716506) surpassing helicopter emergency landing loads have been performed on the hull shell and its composite helicopter deck for proving the resilience of composites to harsh marine environments. The impacted area on the hull shell is shown in Fig. 1(c).

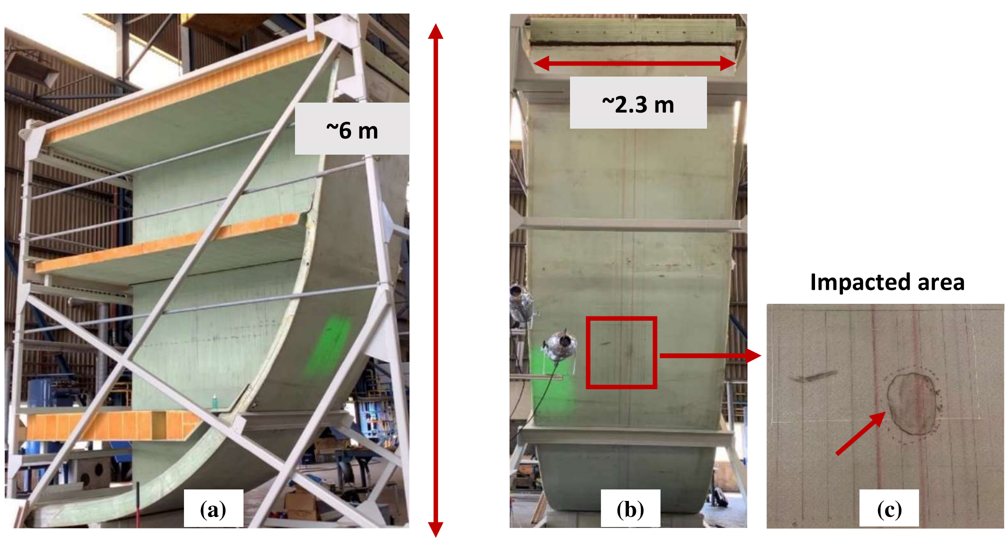

Figure 1 The composite ship hull section at Damen Shipyards: (a) Overall view. (b) Front view. (c) The area with multiple impacts on the hull shell.

In this study, shearography was used to perform NDT of the large-scale composite ship hull section. Its theory and operation principle are well reported in [6,7,9]. For this experiment, the shearography instrument [Fig. 2(a)] was adopted to measure the out-of-plane displacement derivative in a location where defect-induced deformation is expected to be high. Both thermal and mechanical loadings were applied for shearography NDT to evaluate their corresponding efficacies in defect detection.

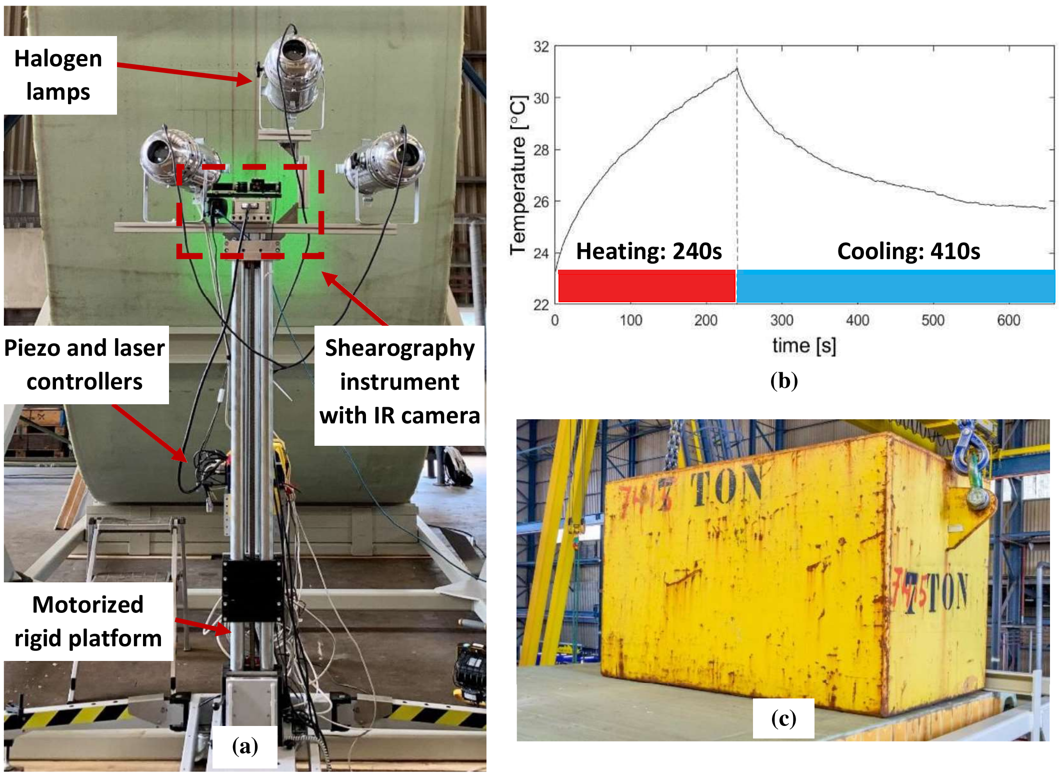

Figure 2 Testing campaign at Damen Shipyards: (a) Experimental inspection system. (b) Average temperature profile from thermal loading. (c) Applying mechanical loading.

The hull shell was illuminated with a Torus 532 laser source (optical power of 500 mW and wavelength of 532 nm) through a beam expander [Fig. 2(a)]. The formed speckle image was captured by a Pilot piA2400 camera with Linos MeVis-C 1.6/25 imaging lens and a Thorlabs bandpass filter through a Michelson interferometer. A piezo-electric actuator PSH 4z from Piezosystem Jena was used to enable temporal phase-shifting (three-step, 2.8 s per phase-shifting cycle). The shearing distance is about 9 mm (~34 pixels) in the vertical direction, which was determined experimentally to produce reliable phase maps for defect detection. During the testing, the shearography instrument was fixed on a motorized rigid platform. By adjusting the rigid platform, scanning in both horizontal and vertical directions can be achieved, enabling a large-area inspection.

Thermal loading was performed by three halogen lamps, each operating at full electrical power (1000W) [Fig. 2(a)]. During heating and cooling, the surface temperature of the hull shell was monitored with a FLIR A655 thermal infrared (IR) camera. The fields of view (FOVs) were inspected by repeating the same thermal loading [Fig. 2(b), 240s of heating], while the average temperature increase of the heated area was about 8 °C. Mechanical loading was done by placing a 7-ton metal block on the structure [Fig.2(c)], which corresponds to the landing of a medium-sized helicopter.

3. Results and discussions

3.1 Shearography inspection results

The experimental results with thermal loading are shown in Fig. 3. A total area of about 1500×900 mm^2 was inspected by stitching six FOVs of 600×600 mm^2 [Fig. 3(a), 2 in the vertical direction by 3 in the horizontal with about 20% overlap for stitching]. Phase-shifted sets of speckle images were captured continuously during cooling. All sets of the recorded images were analyzed and stitched together to produce built-up phase maps of the whole area [Fig. 3(b)] that represent the evolution of the surface out-of-plane strain during cooling. The resultant phase map was further processed to obtain the compensated phase map [Fig. 3(c)], where the defect-induced deformation was extracted [10]. This compensated phase map reports the presence of damage in the structure. The stitching process can be further improved by considering the shape of the surface, the positions of the camera and the laser [13]. The damage in the impacted region is not obvious, this can be because its position is close to the edge of the FOVs no.5 and no.6, which makes it difficult to extract actual defect deformation.

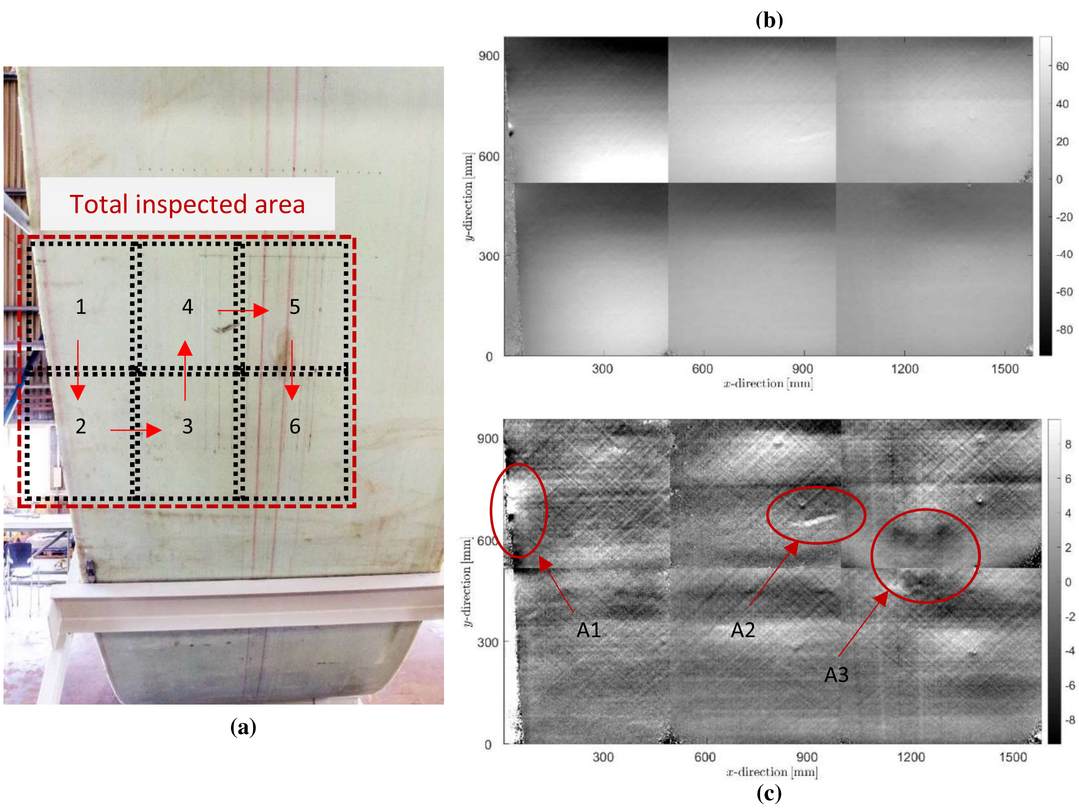

Figure 3 Stitched inspection results for six FOVs with thermal loading: (a) Total inspected area (FOVs no. 1-6). (b) Origin phase map. (c) Compensated phase map, A1 - skin-to-core debonding, A2 - heat damage, A3 - impact damage of interest. [Unit of phase is radian]

The results of the detailed inspection of the impacted area are shown in Fig. 4. Both thermal loading and mechanical loading were applied for shearography NDT. The compensated phase maps with thermal and mechanical loadings are shown in Figs. 4(b) and 4(c), respectively. The impact damage (shown as strain anomalies in compensated phase maps) was detected successfully from both thermal and mechanical loadings in the same region, which indicates the reliability of shearography. These strain anomalies are expected to be due to delaminations and potential skin-to-core debonding in the thick structure.

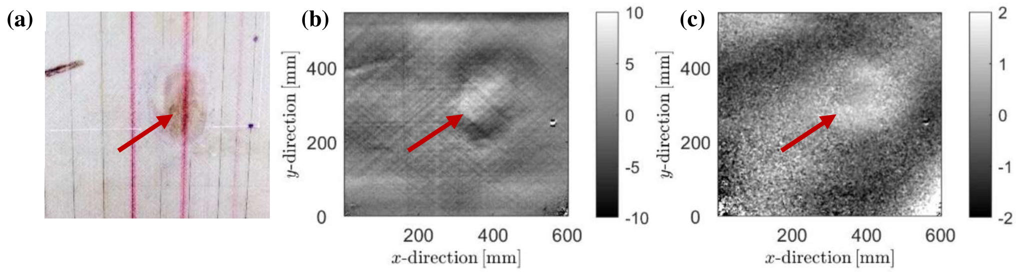

Figure 4 Detailed inspection of the impact region (a) The inspection area with multiple impacts. (b) The compensated phase map with thermal loading. (c) The compensated phase map with mechanical loading. [Unit of phase is radian]

3.2 Discussion

The principle of shearography NDT relies on deformation changes of the test object surface. Therefore developing shearography NDT operation eventually becomes developing a suitable method of loading to deform the object that can reveal defects [9].

For thermal loading, it is easy to apply, and loading parameters such as intensity and time of heating are easy to control. Uniform heating can be useful to inspect a large structure. Nevertheless when inspecting deep defects, e.g. deeper than 20 mm, more time is required for heat to propagate (tens of minutes). It can be noted that heating lamps can cause hot airflow during heating and cooling which should be treated carefully in experiments.

For mechanical loading, it is possible to reveal critical defects only and to avoid trivial defects if the test object is loaded in a similar stress state to the actual working load in-service [9]. One possible advantage can be fast measurement time as heat propagation is not needed. However, the deformation of the test object is difficult to estimate in experiments. Suitable loading increments need to be determined for shearography. The loading process usually introduces large rigid body movements that may cause unfavorable speckle decorrelation in shearography. This was observed during the inspection. The unloading process is found to be acceptable in experiments for producing reliable phase maps. The challenge is to develop an adequate mechanical loading scenario to obtain the detectable defect-induced strain. For this, prior numerical modelling can be done to give an estimation of the needed load for expected critical defects.

4. Conclusions

This experimental study of the composite hull section demonstrates that shearography can be a suitable NDT technique for large-scale composite structures of significant thickness up to 50 to 200 mm. Both thermal and mechanical loadings were evaluated for shearography NDT. Compensated phase maps from the two loadings both identified the presence of impact damage successfully. Uniform heating can be useful for inspecting a large structure with shearography, however significant time, e.g., 10 to 20 minutes, can be needed for heat to propagate when inspecting deep defects. Mechanical loading is possible to reveal critical defects directly and fast in speed, nevertheless, one precaution is to avoid excessive rigid body movements. Future work can be to determine suitable mechanical loading increments for shearography and to study the detection capability of shearography with mechanical loading.

Acknowledgements

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