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USING NDT METHODS IN MARINE COMPOSITE STRUCTURES – CASE STUDIES

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Non-destructive testing (NDT) is gaining increasing importance in the marine industry, with its application expanding beyond aviation into composite yacht manufacturing. This paper presents selected case studies using ultrasonic pulse-echo, infrared thermography, and laser shearography, performed on representative GFRP samples as well as real-world marine structures. The discussed examples highlight the challenges specific to thick composite sections, diverse defect locations, and the need for image-based evaluation systems. The selected cases address problems encountered by yacht manufacturers and attempt to indicate possible solutions.

Keywords: NDT, marine, composites, ultrasonic, infrared thermograph, laser shearography, case studies

INTRODUCTION

Non-destructive testing (NDT) is applied across many fields of engineering. One of the best examples of an industry where NDT is fully established is aviation. In this sector, NDT is required by manufacturers (OEMs) due to regulatory demands. These regulations also define requirements for the personnel performing NDT. A three-level certification system is in place, under which each successive level requires proof of relevant training hours, practical experience, and demonstrated competence verified through examinations. In ongoing practice, certified inspectors are subject to periodic assessments and re-certification, depending on their certification level. In contrast, composite yacht manufacturing is not governed by regulations mandating NDT. However, initiatives are emerging that aim to standardize best practices as well as develop recommendations and technical guidelines. The motivations behind these efforts are diverse and were clearly articulated in a BINDT report on NDT for Marine Composites [1]. The reasons are numerous, starting with the most important one – crew safety.

A strong illustration of the risks involved is the Cheeki Rafiki yacht accident, which occurred 720 miles southwest of New Scotland. The yacht lost its keel, leading directly to its sinking, and the crew did not survive. This case is now one of the most frequently cited examples underscoring the need for thorough testing of bonded joints in yachts.

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Another key driver is cost. Given the high value of components such as composite hulls and masts, insurers are increasingly motivated to reduce risk through quality assurance provided by NDT during production. The aforementioned report provides concrete figures: among 1,000 insured high-risk racing yachts, 130 claims were paid out, totaling £12 million – 27 of which were due to composite damage. Of those, only seven yachts had undergone prior NDT inspections. The losses, much of which could have been prevented, were substantial.

Some regulatory actions are already underway. The UK Ship Register issued the report “Information and Guidance Report, targeted at the examination and inspection of carbon fibre masts and spars of large commercial yachts built under the MCA Large Commercial Yacht Code” [2]. The document includes essential inspection guidelines.

Considering that companies specializing in yacht inspection can already be found online and that press reports increasingly mention NDT applications in the yachting sector [3], it can be concluded that NDT practices are gradually gaining ground within the marine industry.

AIM AND SCOPE

The chemical modifications of the waterborne polyurethane coatings presented in this article were performed with chemical modifiers from the group of multifunctionalized organosilicon compounds (MOD) synthesized in-house. A spherosilicate core was used and functionalized with three different functional groups with varying molar ratios, presented in Table 1. Additionally, a pure polyurethane coating without any modifications was utilized for comparison purposes as a reference sample.

NDT methods in marine composites

Based on published research, the most commonly used NDT methods are listed below. These are not the only techniques employed – some studies also mention methods such as microwave inspection [4]; however, the three methods listed below remain the most frequently applied [16, 17, 18]. For comparison, the authors conducted tests using these methods on the same sample made of glass fiber reinforced polymer (GFRP) produced by the infusion process. The total thickness of the sample was 20 mm, and the simulated defects were located at a depth of 8 mm. The choice of this sample was deliberate: the material and manufacturing technology are widely used in the yacht industry, whereas most scientific literature on NDT methods is based on materials and technologies used in aerospace applications – where lower porosity levels and thinner structures are typically encountered. These two parameters significantly influence defect detectability [18, 19]

Ultrasonic pulse-echo

The ultrasonic pulse-echo method is the most commonly used non-destructive testing technique because it allows inspection with access from only one side of the surface [4]. Composite manufacturing factors such as reinforcement content and porosity affect signal attenuation [6, 7]. Depending on the thickness and attenuation, the frequency range typically varies between 0.5 and 10 MHz. [5]. Higher frequencies provide greater sensitivity due to shorter ultrasonic wavelengths, while lower frequencies yield reduced sensitivity but allow deeper penetration into the structure. [8]. Since contact between the probe and the inspected surface is required, a coupling agent must be used. For hand-operated A-scan probes, gel is typically employed, whereas for two-dimensional (C-scan) mapping or phased array systems, water is more suitable. The ultrasonic method can deliver detailed information about defect size and depth.

Nevertheless, one limitation of this method is the time needed to conduct it. When using handheld equipment, signals are collected by means of a relatively small probe, which lengthens the inspection process. Scanners and phased array instruments can operate faster, provided that coupling is maintained properly. In practice, the shape and surface smoothness of real structures can make coupling difficult.

The ultrasonic testing (UT) method is particularly sensitive to porosity, voids, impact damage, and disbonds. A significant advantage of UT is its ability to detect defects located relatively deep beneath the surface. Figure 2. presents the results of UT phased array testing performed on a reference specimen (Fig. 1) using DolphiCam2 equipment.

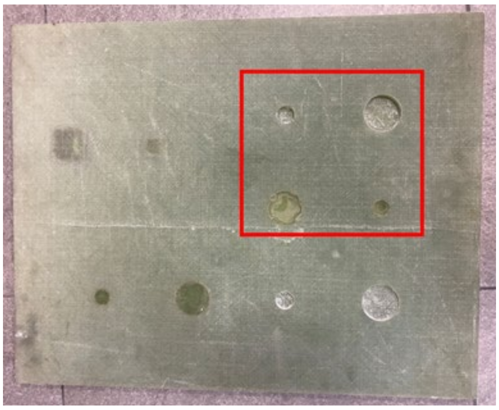

Fig. 1. Composite sample used for method comparison. Sample was manufactured at yacht shipyard using technology and materials applied in yacht production. Inspection area is marked with red box

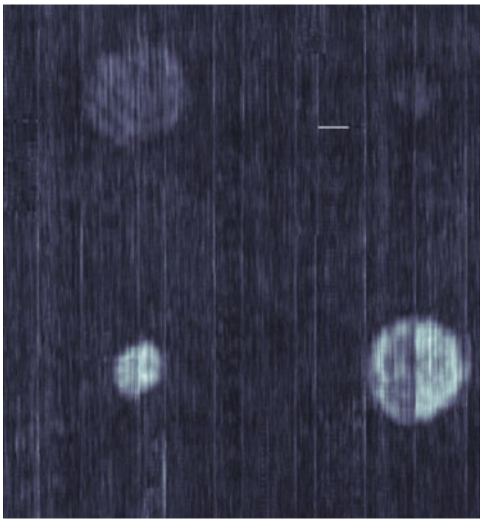

Fig. 2. Results of ultrasonic phased array test of sample from Figure 1

Thermography

The thermography method is a contactless NDT technique that allows the visualization of heat distribution on the inspected surface [9]. Depending on the equipment used, thermography can be performed in two modes: active (with an external heat source) or passive (camera-only observation). Most defects represent discontinuities with thermal properties that differ from those of the base material in the composite structure [10]. In active thermography, heating of the surface generates temperature variations that reveal the presence of damage. The heat input must be applied uniformly over the inspected area. Common heating sources include infrared lamps, hot air guns, and flash lamps. The most typical damage modes detectable by active thermography include voids, delaminations, disbonds, and entrapped moisture. Such defects usually appear as localized areas of increased temperature, except for entrapped water, which appears cooler due to its high heat capacity.

The relationship between the actual defect size and its thermal indication depends on both the defect depth and the thermal properties of the material. Specific techniques such as flash thermography are best suited for thin laminates, whereas pulsed phase thermography can be applied to thicker laminates, though increasing thickness significantly reduces the signal-to-noise ratio (SNR) [11]. On the examined sample, it was possible to obtain clear indications from the flat-bottom holes at a depth of 8 mm, and almost invisible indications from the holes at the same depth that were filled with resin (Fig. 3).

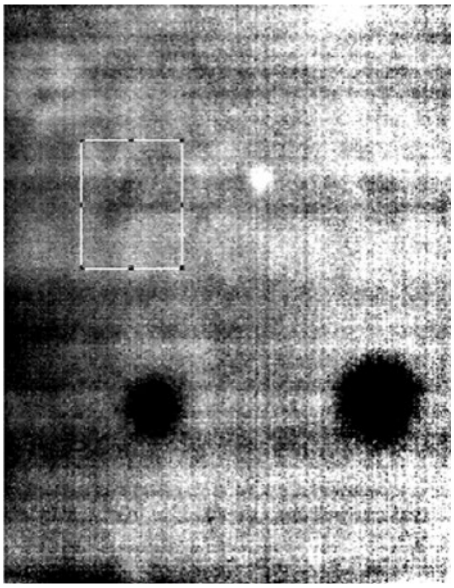

Fig. 3. Result of thermographic test of sample from Figure 1

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Shearography

Like thermography, shearography is a contactless and real-time NDT method. The principle of the technique is based on laser interferometry. A coherent laser beam is expanded to generate a speckle pattern on the illuminated surface. This pattern of scattered light is reflected from the surface and captured by a CCD camera utilizing an image-shearing device [12, 13]. After the object undergoes slight deformation, a second set of images is recorded. The difference between the two captured states enables the reconstruction of an interference fringe pattern that represents the displacement derivatives. Shearography is highly sensitive to out-of-plane surface displacements [14]. Defects detected by this method are primarily associated with local stiffness variations, such as disbonds, delaminations, core damage, or moisture ingress. To induce measurable surface deformation, shearography requires an external excitation source, most commonly heating by halogen lamps or the application of vacuum pressure. When using thermal excitation, the indications should be interpreted with caution. In this case, the two upper round indications come from the resin-filled holes, and with the applied approach, they do not differ from the indications from the flat-bottom holes modeling delaminations (Fig. 4.)

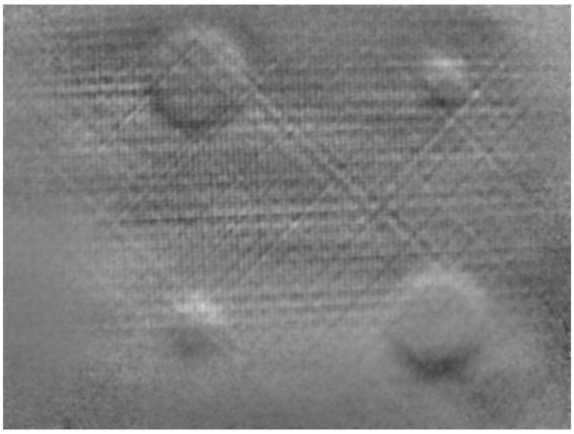

Fig. 4. Result of laser shearography test of sample from Figure 1

CASE STUDIES

This section presents NDT results obtained from real marine structures using the three previously described methods.

Gelcoat blisters detection

Gelcoat blisters are manufacturing defects that manifest as local swellings of the laminate after a hull has been immersed in water for some period of time [15]. In general, blisters are considered cosmetic issues, but they generate repair costs and should therefore not be neglected. This motivates the development of effective detection methods. The following case presents examples of defects that were identified using advanced NDT techniques after having gone undetected in prior visual inspections. Three methods were applied to detect small blisters in newly manufactured hulls.

The first of these, recommended by specialists, was infrared thermography [10]. Inspection was performed on a deck with a complex shape. Due to the complex geometry, manufacturing defects were expected. According to the reference [10], the minimum detectable blister size is 6 mm. Nonetheless, this value is only an approximation since detectability depends on several factors such as gelcoat thickness, camera resolution, and the distance between the camera and the hull. In the presented tests, blisters with diameters of approximately 4–6 mm were successfully detected within an observation area about 1 m wide (Fig. 5). The inspection was performed using CCheck-IR equipment with IrNDT software.

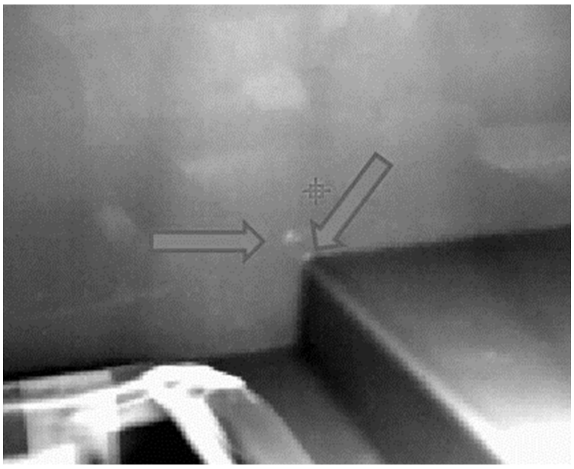

Fig. 5. Thermography results. Bright spots marked by arrows are blisters

The second method employed was ultrasonic testing, performed with a DolphiCam2 using 2.5

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MHz and 5 MHz phased array probes. Because ultrasonic inspection is more time-consuming than thermography, this method was applied to areas where numerous blisters had been detected visually (see Fig. 6). Both the selected ultrasonic frequencies enabled the detection of blisters located on the underside of the gelcoat layer (Fig. 7).

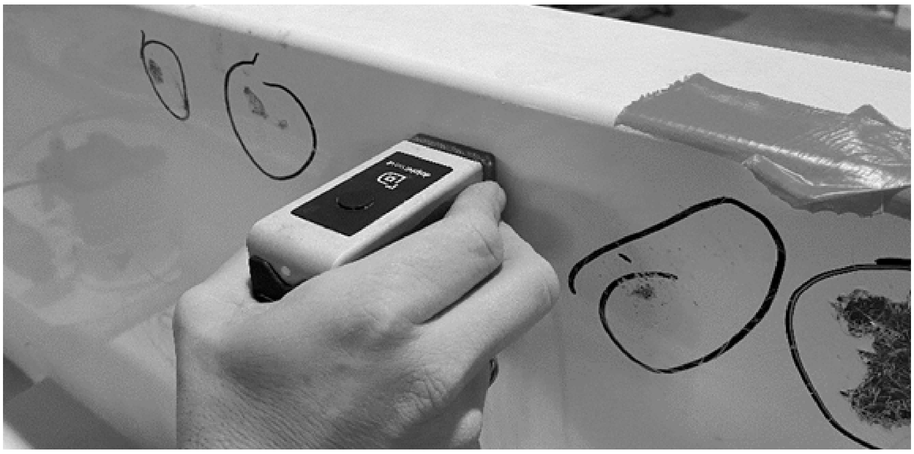

Fig. 6. Inspected area. Left and right side of probe are areas with visually detected blisters

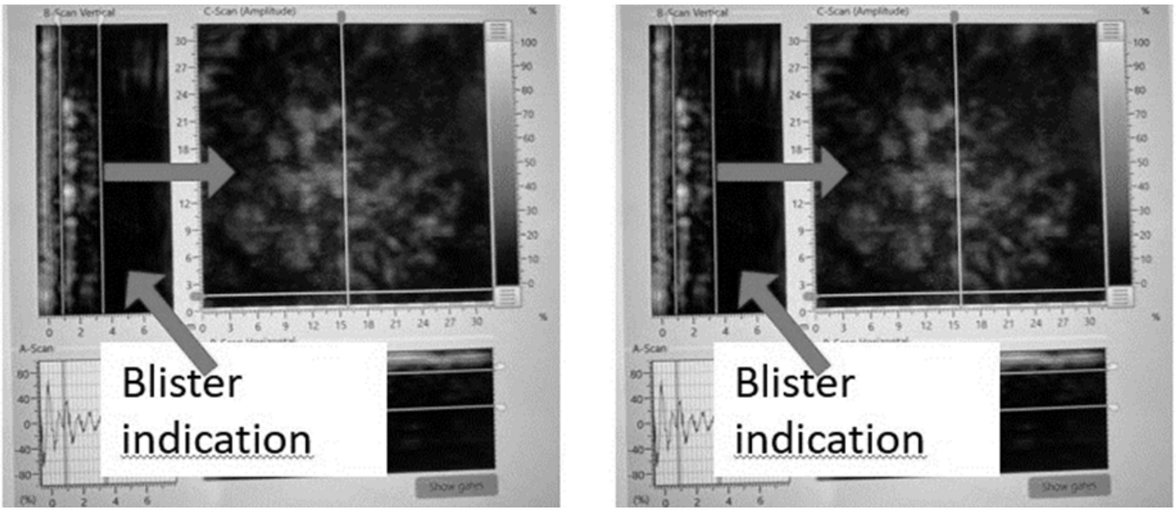

Fig. 7. Ultrasonic indications of about 20 mm diameter blister. 2.5 MHz result left, and 5 MHz result right

The third method presented involves laser shearography. This inspection was carried out using a Dantec Flaw Explorer system with dedicated Istra software. For this test, the outer surface of the hull was examined. Deformation state changes were induced by heating lamps, and the detected defect size was approximately 6 mm (Fig. 8).

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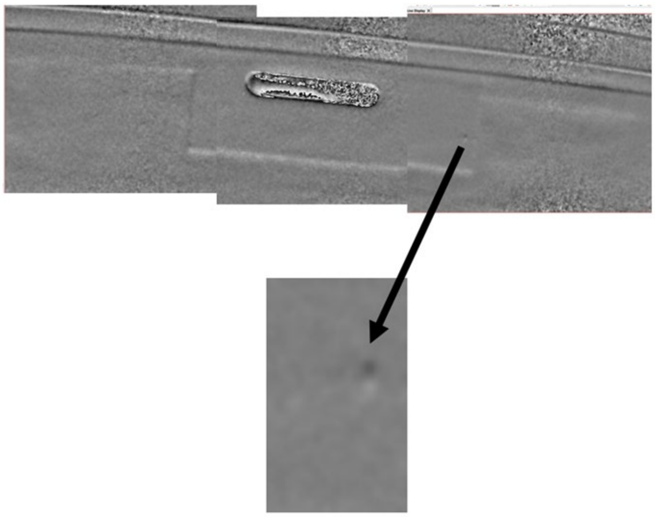

Fig. 8. Blister detected on hull by using laser shearography method

Bowsprit damage identification

The second case concerned damage identification for repair purposes. The bowsprit of a racing yacht had been damaged during a collision. During visual inspection, a small defect was observed on the upper side of the bowsprit. Since the CFRP structure is opaque, the full extent of the damage was unknown and detailed NDT was required. Two methods were applied.

The first method was infrared thermography, which allowed assessment of the damage size and provided a relatively fast means of evaluating other areas of the component. The inspection was carried out using CCheck-IR equipment. As a result, several delaminations caused by the collision were detected on both the upper and lower sides of the bowsprit. The results are presented below (Fig. 9).

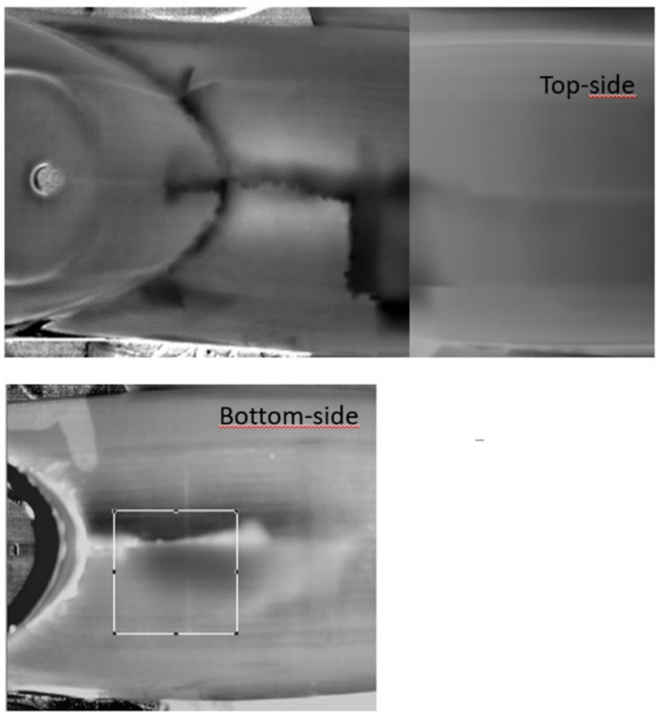

Fig. 9. Results of thermography tests of upper and lower surface of bowsprit. Extensive damage is visible on both surfaces

However, due to the limited depth of penetration of thermography, the depth and size of the detected damage were difficult to quantify accurately. Based on the thermographic results, a UT phased array inspection was performed to determine the exact extent of the damage. The inspection was carried out employing DolphiCam2 equipment with a 2.5 MHz probe (Fig. 10).

Fig. 10. Ultrasonic inspection

Using current C-scan results, the damage boundaries were marked directly on the bowsprit in a step-by-step manner (Fig. 11). Additionally, a stitched amplitude map was generated to visualize the damaged areas.

Damage sizing was later confirmed during the composite repair process, and the repaired component was subsequently reinstalled on the yacht.

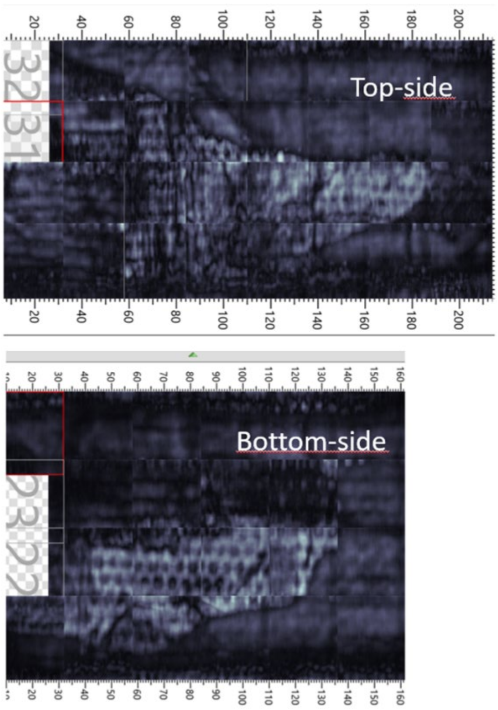

Fig. 11. Ultrasonic C-scans

CONCLUSIONS

The non-destructive testing techniques presented in this article are among the most commonly applied. The methods were discussed using examples of relatively thick composite structures. The presented case studies demonstrate that in the shipbuilding industry, a wide variety of damage types exists, resulting in significant differences in both defect size and depth within the material. These variations are crucial when selecting appropriate methods and equipment for NDT.

Nevertheless, the authors advocate for adopting solutions similar to those presented in the case studies. Their common feature is the generation of image-based results, which facilitates efficient data management and enables further use in applications such as digital twin development.

Greater emphasis was placed on the practical aspects of the applied methods; therefore, the comparative analysis was limited to sample testing. In the presented cases, the choice of methods was subjective. It is easy to imagine how time-consuming it would be to examine the external surface of a 10-meter yacht hull using a phased array probe with an active area of only 30 × 30 mm. On the other hand, deeply located damage – such as those observed in the presented bowsprit case – would be difficult or even impossible to characterize accurately using thermography or shearography techniques alone.

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