Marine Composites **Workshop**

Report from the Workshop on NDT Requirements for Marine Composites

27 February 2018

St Mary's Stadium, Southampton, UK

BINDT
THE BRITISH INSTITUTE OF NON-DESTRUCTIVE TESTING

...engineering safety, integrity & reliability

Workshop on NDT Requirements for Marine Composites

Chair: Robert Smith, Professor of NDT, University of Bristol, and Past President of BINDT

While a significant amount of non-destructive testing (NDT) is already performed on marine composites, the sector needs further support in a number of areas, including the development of NDT acceptance criteria at the design stage for manufacturing and in-service defects, guidance on appropriate NDT method and inspection process selection and new techniques for utilising NDT results for structural integrity assessment. The UK Marine Industries Alliance produced a strategy for growth for the industry[1] and a 'UK Marine Industries Technology Roadmap 2015' document[2], which identified a specific need for a non-destructive evaluation (NDE) process for composites within the Structures and Materials Roadmap, with a target date of 2018 to 2020. The first part of this objective is to identify specific NDT requirements for marine composites and is what this workshop aimed to achieve.

The workshop brought together marine sector regulators, insurers, designers, manufacturers, constructors and operators to discuss the opportunities for, and benefits of, improved and enhanced NDT of marine composites. The aim of the workshop was to generate a document capturing all NDT requirements and 'what success looks like' for future NDT and the link to structural integrity and risk-based inspection management.

The workshop was aligned to the following objectives of the British Institute of Non-Destructive Testing (BINDT)'s Composites Group:

- To capture present, and anticipate future, requirements for NDT of composites and enable a route to the solutions via roadmaps for new technologies.
- To work with the structural integrity, manufacturing and design communities to identify and define mechanisms through which NDT/condition monitoring (CM) can enable optimised composite designs, lower-cost manufacturing or life extension.

A technical panel from academia and industry convened the workshop, comprising:

- Professor Robert Smith, University of Bristol (BINDT Past President)
- Dr Richard Freemantle, Wavelength NDT Ltd (Chair of BINDT Composites Group)
- Richard Hammond, Naval Ships, BAE Systems
- Joe Summers, AEL Airborne
- Andrew Elford, Marine Concepts Ltd
- Michel Marie, Land Rover BAR
- Mayur Jogia, Lloyd's Register EMEA
- Richard Craven, QinetiQ Ltd
- Nigel Keen, National Composites Centre (NCC)
- Chris Minton, Minton Treharne & Davies (MTD).

This technical panel was acknowledged and thanked by the BINDT Past President, Professor Smith, in his opening remarks, as were the UK Engineering and Physical Sciences Research Council (EPSRC) and BINDT for making the workshop possible through their support.

Key participants in the workshop represented regulators (the International Council of Marine Industry Associates (ICOMIA)), insurers (Hiscox MGA, Lloyd's Register EMEA), constructors (BAE Systems, Land Rover BAR), naval architects (Navalmartin Ltd) and manufacturing suppliers (Marine Concepts Ltd). Also represented were academia, High-Value Manufacturing (HVM) Catapult Centres (National Composites Centre (NCC)) and several NDT equipment suppliers and service providers (see delegate list, Appendix A).

In addition to short, invited presentations, a key feature of the programme was focused and facilitated discussion time, through breakout sessions and panel-led discussion. These were carefully recorded and documented. This report provides a summary of those presentations and discussions.

More than 60 delegates attended the workshop, a list of whom is given in Appendix A.

Introduction

Professor Robert Smith, University of Bristol

Professor Robert Smith welcomed the attendees, explained the aims of the workshop and showed the programme for the day, which comprised six sessions:

- Session 1 – Regulator and insurer NDT requirements (at manufacture and in service)
- Session 2 – Industry and user NDT requirements
- Session 3 – Current NDT experience
- Session 4 – Future advanced NDT and structural integrity opportunities
- Session 5 – Breakout session (four groups of 15, ten-minute rotation)
- Session 6 – Panel session.

Professor Smith informed the delegates that the UK Composites Leadership Forum (CLF) had produced a 'UK Composites Strategy' document in 2016, forecasting a potential rise in UK turnover in marine composites from £220 million in 2016 to between £240 million and £270 million by 2020 and a further opportunity to grow to between £320 million and £370 million by 2030. However, there are also some real inspection issues with current composite vessels that would benefit from either improved technology or a more coordinated approach from the NDT industry. The workshop was convened to explore these opportunities and problems with a view to determining NDT requirements for this growing composites sector.

Session 1: Regulator and insurer NDT requirements (at manufacture and in service)

Regulatory requirements for NDT of composites

Ken Hickling, ICOMIA

This session was opened by Ken Hickling, a super-yacht industry specialist, who presented on the regulatory requirements for the NDT of composites within the marine sector. Advanced composites are still becoming established in marine applications, but production quality can easily be compromised. Customers have good reasons to want the benefits of composites, but the risks involved are often unknown or poorly managed. Generally, the responsibility for risk management is routinely pushed onto the vessel owner. Regulation can provide meaningful guidelines and help to manage risk. Within this, NDT will play a vital role and is needed as a contribution to regulatory development so that the rules are well founded on current and future methodologies. The general drivers for the use of composites include performance, cost, carbon footprint, comfort and aesthetics. The drivers for regulation are safety and standardisation (to allow for fair comparison) and those for applying NDT are direct assessment, increased confidence and time savings.

Most composite materials are only created when the product or component is manufactured. Variation in the manufacturing process or undetected damage can lead to significant variation in results and subsequent performance in service. As an example, for carbon fibre rigs, failure rate is currently considered by many to be higher than anticipated or desired. Destructive testing is useful only at the product development and type approval stages because testing one component or element will not tell you if another has been made correctly or has been damaged after manufacture. In this situation, NDT is valuable to indicate whether the outcome is what you expected. NDT can confirm the condition of the component in three important areas: manufacturing quality assurance, correct installation and then in service.

Figure 1. Examples of composite structural failures

Existing regulations do not cover this area well. The hull is covered by ‘Class Rules’ but the flag nation is responsible for safe operation. There are suggestions that existing guidance notes and Class certifications covering this area miss the reality that design and analysis can only tell us if the component should work within the defined performance envelope. But this is not an assessment of the product itself, only of the design. The Maritime and Coastguard Agency (MCA) is strong on procedure but guidance from 2011 states: ‘5.1.1. There are currently no published standards which specifically cover the non-destructive inspection of carbon fibre laminates.’ Further to this, regulations are often out of date, so prescribed test methods can fall behind emerging technology. Where safety is the issue, this is frequently addressed through large design safety factors that are often inefficient and second-guess quality. Lastly, the required levels of competence for inspectors and assessors has not been defined in the marine composites context.

ISO Technical Committee 8 – Ships and Marine Technology, Sub-Committee 12 – Large Yachts (> 24 m), has a series of working groups, one of which is WG 5 – Quality Assessment and Acceptance Criteria. This group is looking at how to define a practical method for assessment/survey to determine whether a composite component itself is fit for service. Regulations should be pragmatic, affordable, indisputable, clear in their guidance and valuable to industry. However, to achieve this, NDT methods must be reliable and reproducible. With clear definitions of methods and relevant competencies, we can move from the current position, where there are high levels of uncertainty, variability and risk, to a future in which owners are confident, crews are safe and product performance is reliable.

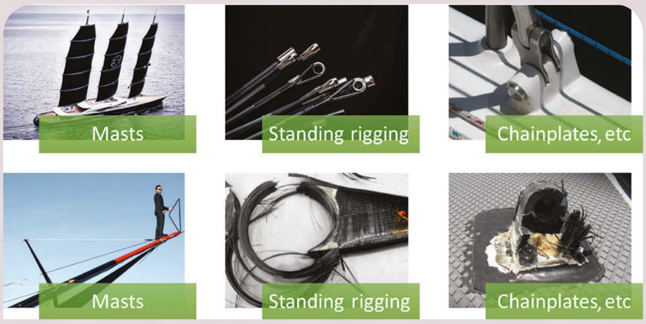

Figure 2. Examples of composite rigging components (top) and failures that have occurred in these (bottom)

NDT of marine composites – an insurer’s view

Paul Miller, Hiscox MGA

Unfortunately, Paul Miller was unable to attend the event due to inclement weather. However, Dr Richard Freemantle, Wavelength NDT Ltd, presented on his behalf about the current insurer requirements for NDT of composites. The presentation concluded that mast and boat production was now becoming so expensive that insurance agencies were looking to mitigate future risk through the use of NDT inspection techniques by insuring against in-built latent defects that may prove catastrophic at a future point in time.

One of the main areas for concern as an insurer is that the marine industry still appears to be largely a cottage industry when it comes to NDT and we are not embracing the benefits of NDT in the manufacture of composite structures. In their experience, there are no set NDT survey standards or industry agreements on acceptable defect size. Another area for concern is that several classification societies provide a certification process for the mast, which is often mistaken for full classification. The certification process only involves re-checking the finite element analysis (FEA) data and does not include a detailed physical inspection of the structure.

In recent years, yachting has taken a huge leap forward with foiling, increased boat speeds, the quest for lighter structures, thin-ply technology (TPT) and, consequently, the rapidly accelerating costs of new racing yachts. With all of this in mind, the industry needs to be educated on the benefits and correct use of NDT in order to mitigate composite failures.

For insurers, the NDT process is about trying to eradicate build faults and, for all risks that we insure with carbon masts, we request a 100% NDT inspection of the mast at inception and annual checks, dependent on the amount of racing that the vessel has taken part in. We look to obtain an independent review of the structure, quality control, comfort and the ability to create a record log that will track anomalies throughout the life of the structure.

An ISO NDT survey standard would be hugely beneficial to the industry; at present there are too many unqualified surveyors offering cheap and ineffective NDT services to which the owners are attracted due to the low costs. NDT is currently seen as an unnecessary evil imposed by insurers and the insured do not understand its true benefits.

Since 2007, we have insured in excess of 1000 high-risk racing yachts. Within this period we have paid 130 claims totalling £12,000,000; 27 of these claims have been identified as being due to composite failure, only seven of which had NDT inspections. If the other 20 risks had undergone NDT, the anomalies may have been identified and repaired and may not have resulted in a failure. Approximately one third of all Class 40 claims are due to mast failures, which led to us introducing NDT inspections for all Class 40 yachts in 2016. In 2017, we also introduced a Class 40 NDT schedule to help owners to include this in their schedules and budgets.

In our view, the industry has yet to embrace the benefits of NDT and the introduction of an ISO survey standard will be a benchmark in raising the professionalism of the industry; education of the yachting industry is key!

The link between NDT and structural integrity: potential impacts on regulations

Professor Janice Barton, University of Southampton

Professor Janice Barton started by reminding the audience about the University of Southampton's recent 'Modernising Composite Regulations' document, published in 2017, where one of the issues addressed was: 'What prevents the take-up of composites in many industries?' In the marine industry, the major barrier was the regulations being based on equivalence to metals, with many hurdles to modifying or working with the regulations. They had looked at the aerospace industry, where composites are used extensively and instead of an 'equivalence' approach they use a 'building block' approach (see Figure 3).

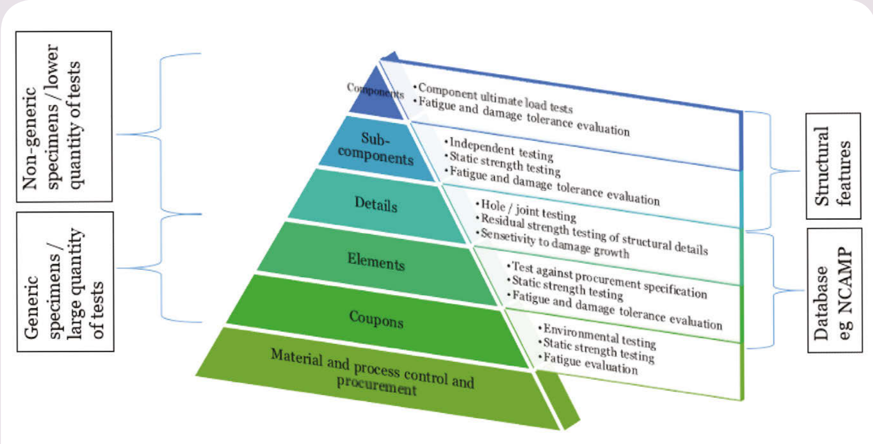

Figure 3. Illustration of the design test pyramid within the building-block approach to certification of composites in the aerospace industry

This approach allows composite materials to be certified and used but it does not apply well to the marine industry due to the large amount of structural testing required, from coupon-sized tests right up to the testing of major structural components.

Professor Barton then talked about a recent feasibility study with colleagues at the universities of Southampton, Bath and Bristol. This combined NDT with high-fidelity instrumented mechanical tests and FEA modelling of component-sized structures in order to re-shape the design test pyramid (see Figure 3) and make it affordable within other industries, such as the marine industry. The primary focus is to test components in the middle of the pyramid using 'high-fidelity testing', where lock-in digital image correlation (LIDIC) and thermoelastic stress analysis (TSA) provide a lot more information about the stresses and strains in a component under test. An example of how this can enable the certification of a wider range of technologies is in Z-pinning of composites that cannot be adequately tested in coupon tests with only in-plane strains applied. The feasibility study concentrated on the corner of a C-spar for an aircraft wing where a very small wrinkle existed near the inside surface of the bend and the loading was a complex combination of bending and shearing due to the location along the spar. The defect caused more than a 50% knock-down in strength for the relevant modes of loading and it was possible to predict this with FEA modelling using a model developed from X-ray computed tomography (CT) data. TSA confirmed the stress concentration factor at the defect that had been predicted by the FEA model. The LIDIC confirmed the strain field predicted by the model. There was good correspondence between the predicted and observed failure load.

For marine composites with larger components and more woven composites, a new EPSRC/industry-funded laboratory (see Figure 4) is being constructed at the University of Southampton, allowing much larger components to be tested on the 30 m × 15 m strong floor, with TSA/LIDIC full-field imaging combined with multi-axial loading. This will allow not just for the detection and characterisation of defects, but also for prediction of the strength of the component, linking it to the structural integrity.

There was a question about the level of investment that would be required to undertake this kind of model-based certification and, even though the modelling approach is cheaper than a full mechanical test programme, it would still be far greater than the marine industry would be prepared to invest. Professor Barton said that the team are aware of this problem and the intention is to find ways to make it affordable for the marine industry by using, for example, multi-scale modelling and generating databases of material properties.

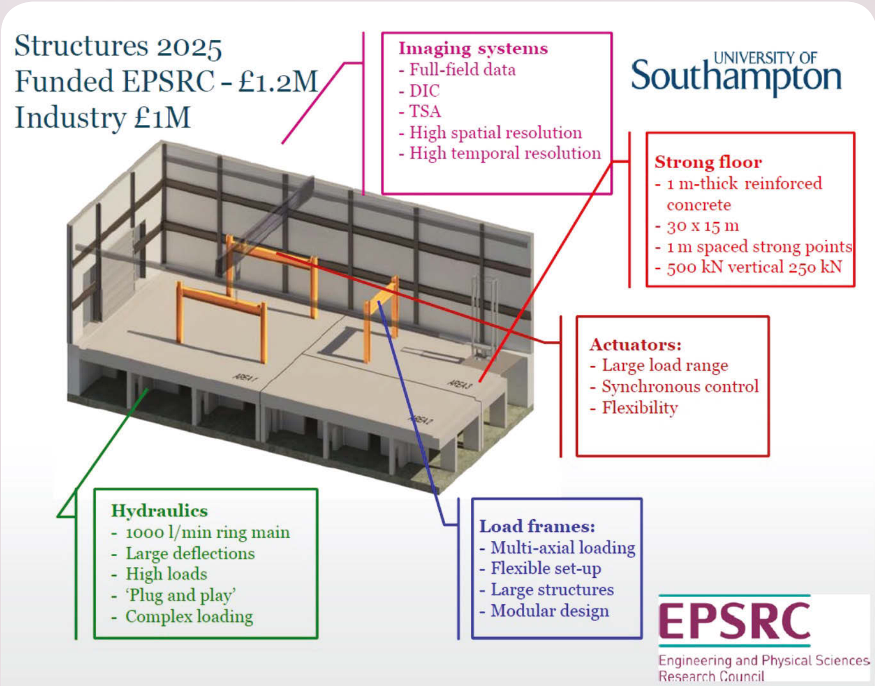

Figure 4. Artist's impression of the new Structures 2025 facility at the University of Southampton

Session 2: Industry and user NDT requirements

High-performance yacht requirements

Michel Marie, Land Rover BAR

The high-performance yacht sector was represented by Michel Marie from Land Rover BAR, who gave an interesting presentation on a part of the industry that leads the way for future composites usage. The America's Cup is the world's oldest international sporting trophy and the pinnacle of sailing technology. Like Formula 1, it is a mechanical sport. However, unlike motorsport, where the vehicle is raced every week or two and can be gradually improved, the America's Cup is raced only once every four years. The challenge is that, after four years of development, the structure has to perform correctly only once: in the race. NDT is applied in the design, manufacture and in-service phases of the race boat's life.

The 35th America's Cup was raced in 50 ft foiling catamarans with a 'wing sail' (see Figure 5). The technical freedom was limited to the hydrofoil design, the control systems, the wing structure and the aerodynamics of the platform. All of the power generation was human driven and used to control the 'flying surface'. 'Fly by wire' has been prohibited and the helmsman was constantly in the control loop of the yacht, which was capable of speeds of up to 85 km/h.

50 technical staff at Land Rover BAR are designing the yacht. The team includes naval architects, performance prediction and data analysts, fluid dynamists and CFD engineers, structural and composite engineers and mechanical hydraulic and electrical design engineers. The America's Cup is a 'moon shot'; we have one chance to get it right! It is a technical race with leading-edge advanced technology. There is limited opportunity to perform physical tests and the regulation constraints and safety criteria add complexity to the tremendous time pressures.

NDT use in the America's Cup spans all through the campaign, from the initial design phase to the final race period. In the design phase, NDT equipment is calibrated at coupon level and used to characterise designed defect sizes and set acceptance criteria. During the manufacturing phase, NDT is used to sign off manufacturing processes. In the event of non-conformity, defect sizes are measured with NDT tools for further FEA. Finally, at the end of the manufacturing phase, NDT supports the proof loading/acceptance structural testing. Once the yacht is launched, NDT is used during the service phase for health monitoring of structural components, assessment of damaged areas and sign-off on repairs.

Combined with NDT, structural testing is an integral part of the engineering process. At coupon level, structural testing characterises the material properties and design allowables. At substructure level, it signs off the manufacturing processing methods and the analysis correlation. At component level, it is used for the proof loading and acceptance testing, the performance correlation and the instrumentation calibration. At assembly level, structural testing is part of the proof loading and the systems testing.

The base of the NDT toolbox is ultrasonic equipment. We use A-scans and phased array scans as our primary tool for spotting defects requiring further analysis. Some reference phased array scans are created for service phase monitoring. During the proof loading/acceptance structural testing and the final acceptance at the end of the manufacturing phase, thermography, acoustic emission and tomography are used (depending on the size of the parts).

Looking at the next challenge for the 36th America's Cup, the NDT tools will need to improve the rapidity at which we map impact damage and close the loop on FEA models to determine remnant life and structural performance more accurately.

Figure 5. The Land Rover BAR America's Cup racing yacht

Leisure/commercial sector requirements

Dr Daria Cabai, Navalmartin Ltd

Dr Daria Cabai is a designer of vessels, a naval architect specialising in damage stability, working for Navalmartin Ltd. The company designs small, fast motor vessels and also, recently, a 52 m carbon fibre composite yacht. The whole design, engineering, manufacture and construction is complicated and very involved.

Classification societies work with the designers and manufacturers and in shipyards, for all vessels except high-performance yachts. Designers also act as expert witnesses in cases of accidents and are involved with the requirements of the insurance industry. There are a lot of questions to be asked regarding structural integrity during the design, manufacture and certification of a vessel, as well as for accident investigations and salvage. An example was given of a yacht with a carbon fibre mast that was dismasted and the subsequent six-year investigation involved a global effort with experts from many fields, including NDT. A particular concern and interest is how latent defects can develop under fatigue to failure. This can lead to complex legal cases.

The NDT technology is there but there is no guidance about the point in time at which there should be a regime of inspection to supplement the visual inspection.

For a 47 m motor yacht with a sandwich-panel structure that sank when two years old (the wreck was never found), they acted as experts to establish the cause. They found an NDT survey carried out during the service of the vessel, looked into the sea state at the time of loss and developed static and dynamic load models to determine how it could have led to failure. They produced a convincing scenario for why the vessel sank. Another 42 m aluminium motor yacht was an example of a structure that was not sufficiently supported against the loads and this was demonstrated with modelling.

With smaller yachts, they were involved in post-hurricane damage surveys for salvage and repair. Of the 600 vessels, 50% were lost, 25% were repairable but not viable so written off and 25% were economically repairable. Of those that were repaired, there were some good examples of latent defects with subsequent failures. The question is: 'What NDT imaging can pick up these latent defects?' As in the Marine Accident Investigation Board (MAIB)'s report on the *Cheeki Rafiki* tragedy, which showed that not many people look at the interface between the matrix and the hull, where the bonding is crucial, examples of this were found in the hurricane-damaged vessels.

There are now composite vessels over 30 years old and they are reaching the end of their lives. The second-hand market is seeing a boom in composite vessels and this is a potential time-bomb unless an adequate regulatory framework is put in place. What Dr Cabai would like to see from NDT is education, guidance and a framework for surveyors. An NDT 'utopia' is that the NDT boundary is pushed so that we are not so reliant on structural testing.

Defence sector (naval) requirements

Richard Hammond, BAE Systems

Richard Hammond, from BAE Systems Naval Ships, presented on the use of marine composites in the defence sector. The current use of structural composite materials in the UK marine defence sector is mainly limited to minehunter and mine countermeasure vessels (see Figure 6). These single-skin, glass-fibre structures are inspected on a periodic basis, with defects identified visually and by coin tapping and ultrasound. To access the structure for surveys, the paint is removed, a process that is expensive, time consuming and often results in surface damage to the structure.

Future use of structural composite materials is likely to consist of flat sandwich panels for the mast or superstructure of a larger steel ship to reduce weight and radar cross-section, as typified by the USS Zumwalt-class destroyer. Assuring the integrity of the join between composite and steel through the life of a ship is one of the major factors preventing the wider uptake of structural composite materials. This combination of materials presents a challenge for existing NDT methods, which may be further complicated by the incorporation of other functional materials, such as electromagnetic screening and fire insulation layers, radar-absorbent materials and armour.

Figure 6. *HMS Brocklesby*, a Hunt-class mine countermeasures vessel of the Royal Navy

The environmental loadings experienced by naval vessels are not always predictable; they may be subjected to stresses that are higher than expected as a result of combat or the need to proceed through bad weather to provide humanitarian relief. As such, it is necessary to use NDT techniques to identify a structural baseline, from which changes can be identified to predict the remaining life of the vessel and the performance of combat system sensors. Ships are built and maintained in relatively uncontrolled environments, with suppliers increasingly contracted for availability of the vessels. Suitable NDT methods would have limited impact on other activities, while identifying critical defects, being affordable and, ideally, easy to use on an infrequent basis.

Tidal turbine sector requirements

Joe Summers, AEL Airborne

Joe Summers, from AEL Airborne, was the only speaker from the tidal turbine industry, but these structures are not dissimilar to other marine composite structures and they do exist in similar marine environments (see Figure 7). Like most composite applications, verification of the quality of laminates for tidal turbine blades is critical. However, due to the hydrodynamic loads involved, laminates are typically extremely thick (for example > 250 mm) and with varying construction through-thickness. This makes 'traditional' NDT techniques, such as ultrasound, very difficult as the material types significantly attenuate the signal. Our interest is in developing techniques that can determine quality (void content and/or specific defects) at defined locations in the part in X, Y and Z, which can be used in process and at a reasonable cost.

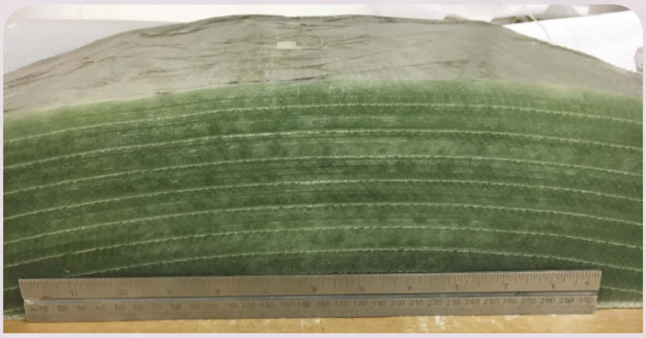

Figure 7. Development tidal turbine component showing material layers

Discussion and requirements capture

Professor Robert Smith, University of Bristol

Often there is no access inside a vessel. Some success has been reported looking at bonding of secondary to primary structure from outside the hull. This is a very useful thing to be able to do – when you cannot get access inside but you can nevertheless determine whether stiffeners and bulkheads are still bonded. Ideally, stiffeners and bulkheads would be inspected too.

Is there any potential for using materials that are easier to inspect? People in the leisure marine market are designing boats to be easier to build; perhaps a change in the design or materials would allow critical structures to be inspected more easily, building consideration of NDT into the design process to allow access to carry out an inspection. In addition to access, changes to the thickness of the layers or level of compaction in composites can also change their inspectability.

For materials that are similar to those used in the aerospace industry, the use of NDT techniques from aerospace could well prove successful for marine applications, such as racing yachts. A bigger problem is the thick carbon/glass high-attenuation materials, where the limitations of current NDT techniques need to be pushed. However, there may be some aspects of hybrid glass/carbon structures that make them easier to inspect for certain defect types.

Having a baseline full map of the structure after build would be really useful for in-service monitoring of the state of the structure. Some work has been carried out on this using manual scans but overlaid on CAD frames. For minehunters, 'hot-spot maps' were generated, probably from visual inspection, to work out where damage was most likely to occur and then to calculate where damage would be more critical. NDT could add to that database of information and it would be beneficial for the Royal National Lifeboat Institution (RNLI), for example, which has a fleet of similar boats. In defence aerospace, an interactive graphical database has been developed for an aircraft type, where NDT data can be stored along with structural damage and repair information for easy recall by clicking on an area of an aircraft map. Insurance companies have been pushing, for fleets of vessels, to map the NDT inspections and information on repairs and incidents and put these into a database.

Session 3: Current NDT experience

Ultrasonic inspection: the challenges of a diverse marine sector

Dr Richard Freemantle, Wavelength NDT

This session focused on defining what is still required to solve some of the challenges with current NDT methods.

Dr Richard Freemantle spoke about the use of ultrasound NDT, including phased array ultrasound (see Figure 8), in the marine composites sector, which presents a challenge to the NDT inspector due to the diverse range of materials, processing methods and laminate thicknesses. Ultrasonic NDT provides information about the bulk properties and about the plies themselves, including the presence of wrinkles. Good imaging of internal microstructure relies on good waveform data, so this is key. In the marine industry, we have specifications telling us how to acquire good data but it is difficult to be specific about a material and its properties due to the diverse range of materials, unlike in aerospace where there are fewer materials and they are well understood.

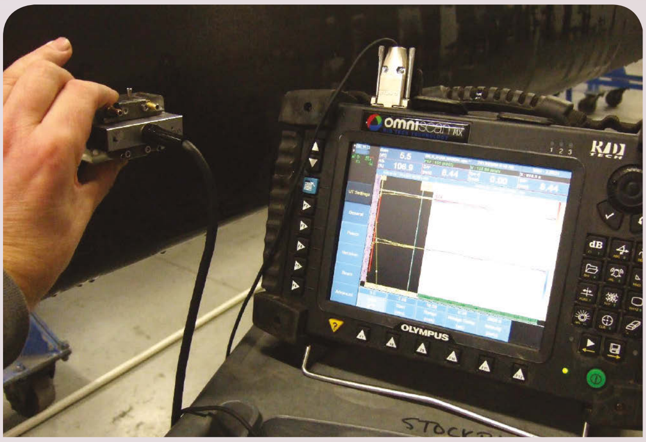

Figure 8. Carbon fibre composite mast inspection using a phased array ultrasound probe

The Maritime and Coastguard Agency (MCA) issued Marine Information Note MIN 417 (M) 'Large yachts: Examination and inspection of carbon fibre masts and spars. Survey of composite masts and spars used on large yachts'. However, this was not very prescriptive and has been shown to be insufficient to avoid problems in various case studies presented by Dr Freemantle. He presented a mast inspection for voids as a means to demonstrate the importance of using the correct ultrasonic frequency for inspection. Figure 9 illustrates how incorrect selection of ultrasound frequency can lead to indications being missed. The higher frequency allowed for identification of layer porosity, which 'failed' the part after microsection confirmation. However, the inspector, who used 2 MHz, had only concluded minor porosity and had 'passed' the component. It is important to pass on any concerns to the manufacturer/designer/owner so that well-informed structural integrity decisions can be made.

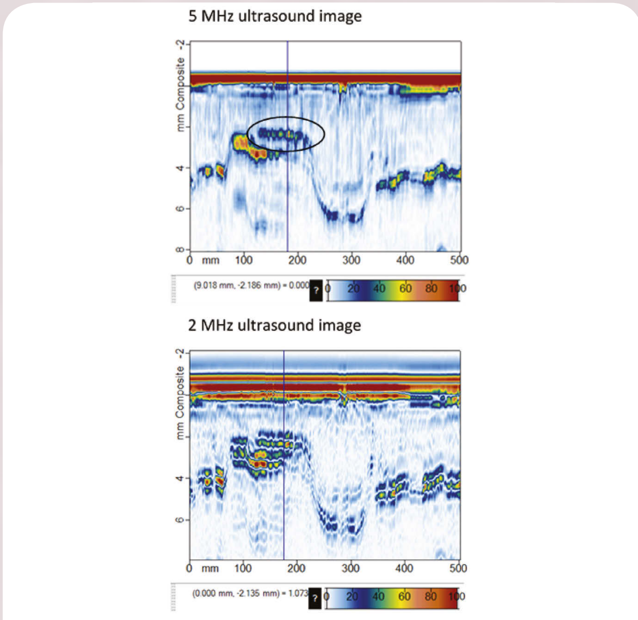

Figure 9. In-service 5 MHz phased array imaging (top) of far surface layer porosity (circled) in a 3.6 mm-thick carbon fibre mast laminate. The indication was previously missed during production NDT due to incorrect (< 2 MHz) selection of probe frequency (bottom)

Enhanced guidance (with input from the various industry stakeholders) is needed to help to ensure that appropriate NDT technologies and inspection procedures are deployed, using suitably experienced and certified inspectors. Dr Freemantle identified several areas in which new guidance is needed for NDT in the marine sector:

- Third-party oversight (independent Level 3)
- Inspector training (Level 2, composites)
- Procedures (documented and approved)
- Techniques (documented and verified)
- Reporting (results can be traced/reproduced)
- Acting on findings (sign-off by designer/original equipment manufacturer (OEM)).

Much of what is required already exists in other industries, such as the aerospace sector, and can be adapted to the marine industry. Standards and NDT certification bodies, NDT training schools and classification societies, have a role to play to allow NDT for a particular sector to be tailored to the materials and structures in use and to help to put in place a regime that ensures safety through structural integrity.

Laser shearographic inspection

Professor John Tyrer, Loughborough University

Professor John Tyrer, from Loughborough University, spoke about the use of laser shearography in the marine sector. He started by referring to MAIB's 'Report on the investigation of the loss of the yacht *Cheeki Rafiki* and its four crew in the Atlantic Ocean, approximately 720 miles east-south-east of Nova Scotia, Canada, on 16 May 2014' (see Figure 10). The report states that "[…] where a GRP matrix and hull are bonded together […] there is a need for regular structural inspection by a nominated competent person as part of a formal verifiable procedure, as well as before embarking on an ocean voyage." Also: "Owing to the continuous nature of a matrix where solid floors are in place, particularly where the keel is attached to the hull, it may be difficult to readily identify areas in which a detachment has occurred. There are differing opinions among surveyors and GRP repairers with regard to the most appropriate methods of inspection and repair, including the circumstances in which the keel should be removed. There is, therefore, a desire for best practice industry-wide guidance to be developed."

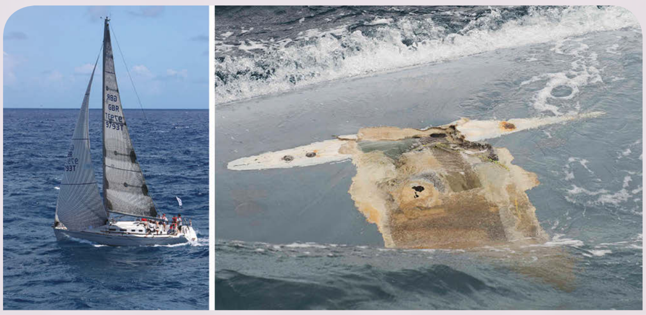

Figure 10. The Cheeki Rafiki, shortly before its loss (left) and capsized (right), showing the lost keel

Figure 11. A hull (brown) and matrix (white) bonded together

As a consequence, Professor Tyrer has explained to MAIB that there are techniques that could have discovered this kind of problem, such as the work he has carried out with RNLI using laser shearography. The ability to measure in-plane strain as well as out-of-plane strain, depending on configuration, mean that clever derivatives of instrumentation are required. No surface preparation is required.

Professor Tyrer has developed and delivered many training courses in laser shearography. His work with RNLI has been successful on both monolithic and sandwich structures. A range of different defect types can be detected over a whole hull scan and repairs can also be validated. A structure can be audited using this method and there is potential for tracking fatigue damage. Carbon fibre rigging may be inspectable in the same way that laser shearography has been used for overhead electric power cables.

There is a need for a certification programme and harmonised approaches to solving these marine composites problems. Standards already exist and can be modified for different applications and there is an opportunity for a PCN qualification for marine composites at least. We need techniques that allow us to see the state of the structure and determine residual life and we need to understand what defect sizes are allowable. In addition, we need to understand and qualify repair strategies. Strain imaging shows that the overall effect of impact damage can be up to three times the size of the damaged area itself. It can also help with residual life predictions.

Thermographic inspection

Dr Rachael Tighe, Defence Academy of the UK

An overview of experience in the development and on-site implementation of thermographic approaches was given by Dr Rachael Tighe from the Defence Academy of the UK. Two main techniques were covered: pulsed/pulse-phase thermography (PT/PPT) and thermoelastic stress analysis (TSA). PT and PPT were demonstrated to be able to reveal a variety of defects found in composite materials and adhesive bonds. Case studies shown (see Figure 12) included carbon fibre-reinforced polymer (CFRP), glass fibre-reinforced polymer (GFRP) and foam-cored sandwich panels with simulated defects. A more in-depth study, assessing the application for the detection of kissing defects in adhesive bonds found in the secondary membrane of liquefied natural gas (LNG) carriers, was also discussed, where detection was aided by the application of a vacuum. The approach was deemed to be fast enough to inspect the 50+ km of joints of interest. PT and PPT were shown to be versatile approaches where the technique could be tailored to the application; several examples were given where alternative heating approaches had been used to reveal defects in different materials or at different depths. Examples of such approaches are given in Figure 12. PT and PPT were shown to identify defect size; however, they do not provide information about the impact of the effect of the defect on the structure. To give more information on how the defect affected the structure, it was shown that it was feasible to use TSA on site to reveal the stress distributions on the surface of the component, thereby giving an indication of the stress redistribution caused by a subsurface defect. It was summarised that thermographic approaches should be in the toolbox of inspection approaches available for use for on-site inspection of composites.

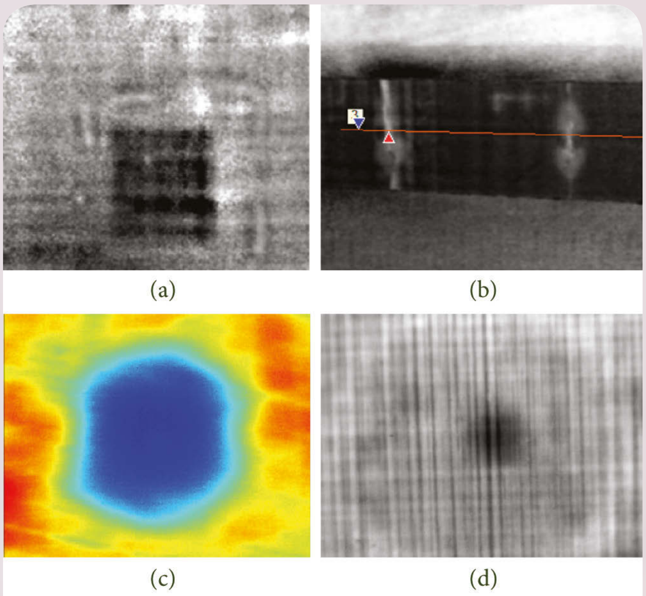

Figure 12. (a) GFRP with foam core sandwich panel with polytetrafluoroethylene (PTFE) insert (heat source – Bowens professional camera flash); (b) GFRP with foam core sandwich panel with low-level impact damage (heat source – Nikon Speedlight SB-600 compact camera flash); (c) composite-metallic hybrid structure (heat source – hot water); and (d) LNG secondary membrane bond with silicon grease contamination to simulate a kissing defect (heat source – Nikon Speedlight, vacuum load applied)

NDT service provision, training and certification

Chris Minton, MTD

Chris Minton, from Minton Treharne & Davies (MTD), described the current scene for training and certification of NDT personnel in relation to marine composites. There are currently no requirements for the qualification or certification of an individual performing NDT on marine composites. This is in stark contrast to the aerospace industry, which similarly uses composite materials to reduce weight and improve performance, where nationally agreed standards exist and are enforced. It would be entirely feasible for an individual without any relevant NDT background or experience to provide an NDT inspection service and sign off a vessel or component as structurally sound, without understanding the nuances of the inspection technique or its limitations. This can result in, at best, a poor reputation for the NDT industry but, more seriously, put lives at risk.

Chris is the Chair of a new committee that is looking to address this shortfall, by considering the requirements of the industry, in consultation with the NDT practitioners and training schools that currently provide certification in other industrial sectors. This committee will initially be focused on the NDT methods: shearography and ultrasonic testing.

MAIB has produced a 'Flyer to the leisure industry: Loss of the yacht *Cheeki Rafiki* and its four crew', calling for regular inspection by nominated, competent inspection personnel. The current practice in the aerospace industry mandates that, for an individual to be considered competent, he or she must perform a specified number of hours in a formal classroom setting, followed by an extensive period of supervised 'on the tools' working. Chris is looking to develop the right programme of training, examination and certification to suit the needs of the industry and produce individuals who are considered competent to carry out inspections.

If anyone wishes to assist Chris in this task, please feel free to contact him at: chris.minton@minton.co.uk

Figure 13. Manual mast inspection

Discussion and requirements capture

Professor Robert Smith, University of Bristol

There was a query about inspecting carbon rods. Solid carbon rods are easier to inspect but the bundled extrusion rods cannot be inspected at present. It is difficult to know whether we can detect lightning strike effects and whether they have had an impact, as every strike is different. A study is required with some samples and a round-robin. Lightning protection systems have been considered but it is still not clear how good they are, which system is best or whether they actually stop damage to the carbon structures. There is a Horizon 2020 project taking place at the University of Southampton for lightning strikes on wind turbine blades, but an understanding is needed into energy dissipation physics and there is an opportunity to read across from the wind turbine industry.

The depth of penetration of the thermal techniques was queried. With the methods presented, there is probably a maximum of 10 mm depth; the deeper the defect, the larger the minimum detectable defect size.

Session 4: Future advanced NDT and structural integrity opportunities

High-fidelity ultrasonic 3D characterisation of composites

Professor Robert Smith, University of Bristol

Professor Robert Smith then presented on 'High-fidelity ultrasonic 3D characterisation of composites'.

First, he explained the aerospace industry's methodology for in-service structural integrity, and hence certification, of composite structures (see Figure 14). NDT is an integral part of this and the result is different certification requirements for defects that can be detected without NDT (clearly visible impact damage (CVID)), those that can be detected with NDT (barely visible impact damage (BVID)) and those that cannot be detected even with NDT. There is a clear benefit in terms of the weight of a structure for a given risk level if smaller defects can be detected. This kind of methodology is not clear for the marine industry.

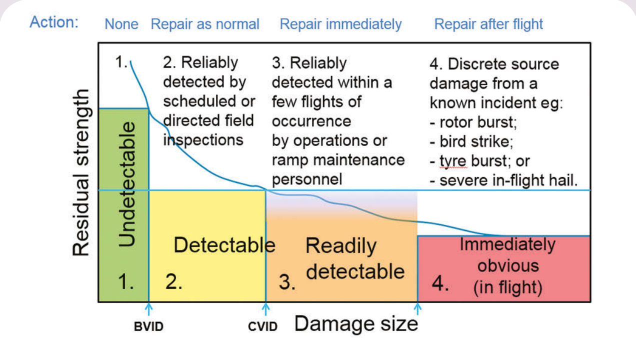

Figure 14. Diagram demonstrating the aerospace structural integrity methodology for certification. Source: EASA AMC 20-29, effective: 26/07/2010

Professor Smith's team is developing methods for inverting the ultrasonic response of a composite laminate to measure and map in 3D various material properties, such as the 3D orientation of fibre tows, local % porosity, ply-drop locations and delaminations from impact damage. In this way, serious defects such as out-of-plane ply wrinkling can be detected, mapped and quantified in a way that will allow better-informed concession decisions to be made at manufacture in-service prior to repair. The technique uses the ultrasonic analytic signal response of the laminate, which has been shown to contain amplitude, phase and instantaneous frequency information that is clearly well 'locked' to the plies in the structure[3]. Ply drops show characteristic changes in these parameters, enabling them to be mapped through the structure. Similarly, out-of-plane wrinkles can be tracked and the angle of the ply measured at each location[4]. Delaminations can be distinguished from resin layers between plies and from 'multiples' of the delamination signal.

The algorithms that facilitate this 3D characterisation will be transitioned into industry as software-engineering documents, rather than libraries of software, via the Manufacturing Technology Centre's new Algorithm Deployment Support Service. The techniques should be available within existing commercial software packages during 2019.

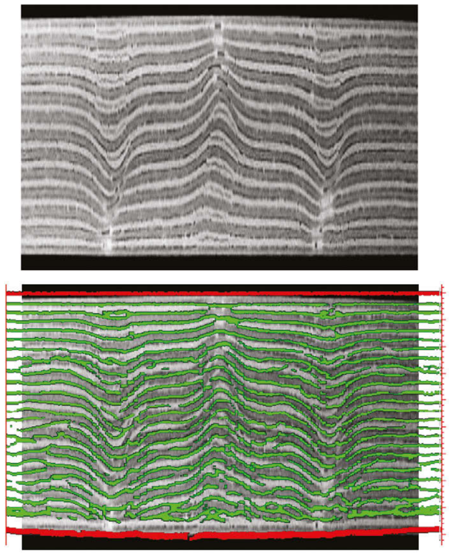

Figure 15. Ultrasonic analytic signal imaging for a specimen containing numerous aligned tape gaps and overlaps, causing out-of-plane wrinkling. The X-ray CT image (top) has an overlay (bottom) inverted from the analytic signal response where red lines are the front and back surfaces, while the green lines are the resin layers between plies, all determined automatically from the ultrasonic full-waveform data[3]

Professor Smith then showed how the maps of material properties generated from the aforementioned inversion algorithms can be used to create finite element models in order to determine residual strength. These models can also be used to determine the metrics that are most indicative of residual strength. Miss Ningbo Xie, Professor Smith's PhD student, had exercised the model to determine that the maximum ply angle is the key metric for a given volume of wrinkled composite[5]. For a particular maximum wrinkle angle, the strength depends on the size of the affected volume. The knock-down in strength is greater for a larger cross-sectional area (perpendicular to the load direction) and for a smaller wrinkled region in the load direction due to an increased stress concentration. This information has not been published previously.

Modelling of defects and failures in structural composites

Professor Stephen Hallett, University of Bristol

As Professor Hallett could not make the meeting, Professor Smith gave the presentation. He proposed that, as the modelling capability for composite structures advances, there is also an increased drive to include more numerical simulation as part of component certification (Figure 16). A risk in using data from small-scale coupons for structural-scale simulations is that the as-manufactured condition of the material may not be captured. Thus, additional empirical knock-down factors need to be included, potentially leading to less efficient designs and significant testing still being required. High-fidelity finite element analysis is now well developed and is capable of being used as a virtual test to replace physical experimentation for understanding the effect of defects on mechanical performance[5]. This talk presented a range of case studies in which state-of-the-art modelling techniques have been used to predict the failure resulting from defects such as wrinkles, automated fibre placement (AFP) gaps and overlaps, embedded delaminations and low-velocity impact.

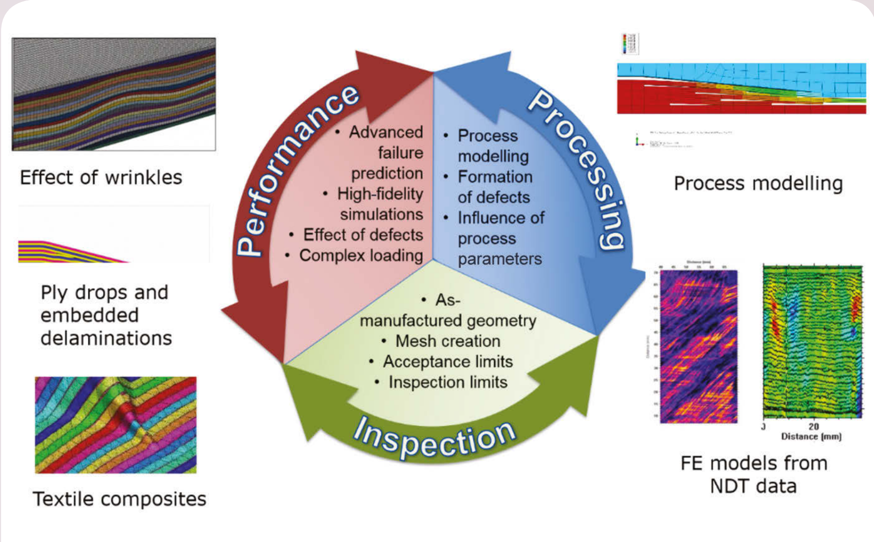

Figure 16. Illustration of the use of NDT information to improve the modelling of as-manufactured components

Future challenges include how to model a full component when just modelling a small defect can take half a million elements. There are various methods proposed for putting fine detail of defects into large models of large structures and homogenised models or shell elements may prove useful to bridge the micro-/meso-/macro-length scales. There is potential to reduce the statistical variance in mechanical testing for certification and in validation of modelling methods by modelling the as-manufactured component, rather than the as-designed component. Moving these methods to 3D woven textiles is a challenge that is currently being addressed by the team at the University of Bristol.

Discussion

A balance is required between the complexity of NDT and what the market actually needs, so as not to scare the manufacturers from innovating and using new technology. Professor Smith discussed the need to identify and target where there is a clear benefit. At present, the driver that is being targeted in the aerospace industry is the concession process – providing more information to better inform the scrap/concede/repair decision process. There is a great benefit in being able to understand the fitness for purpose of the as-manufactured components.

Regarding the affordability of modelling, Professor Hallett also identified the need for large numbers of processors. Professor Barton talked about innovative modelling procedures that rapidly solve complex multi-scale problems. Professor Smith mentioned that using these modelling capabilities in the marine industry could provide benefit in confirming that full NDT inspection is unnecessary at manufacture. It was mentioned that most of the people at the workshop were from the 20% high end of the industry, whereas there is 80% of the sector where no NDT budget is available at all and they operate with very low margins. However, there is not one answer for everyone and it was pointed out that starting at the high end in order to perfect the technology and reduce its cost means that it could be rolled out to the other 80% of the market in the future. But this needs to be a global solution.

Session 5: Breakout session

In-service NDT in high-performance vessels: primary *versus* secondary structure

Lead: Dr Richard Freemantle, Wavelength NDT Ltd

When considering the use of regulation to drive the use of NDT, the key issue is the risk associated with a failure; primary structure, by definition, has a higher risk of failure. Regarding classification by classification societies, in addition to a certified design, there is a need for a process to check construction by performing NDT and witnessing manufacture and installation.

There is little OEM-led information on how to test a component. MAIB should be defining the standards. There should be a service manual and at best there would be recommended inspection intervals and processes. This needs to be mandatory, with the OEM taking responsibility for it.

When considering who bears the cost of NDT, the key is why NDT is being performed: for safety. The cost should possibly be shared between the OEM and the owner. Additional engineering costs are incurred from determining the effects of defects. More information is needed from OEMs to help with this.

A proposal was described for safety-led regulations with potential for the OEM to be required to provide something more than the current warranty: guaranteeing over longer periods by inspection. Risk of prosecution would be a significant and crucial driver, possibly involving the Health and Safety Executive (HSE), for example. This would not just be in terms of the quality of what the OEM manufactures, but would also cover in-service NDT. Regulation defines the correct way to carry out a task, but the risk of prosecution or other consequences of not following regulations or procedures are needed as a driver to conform.

NDT in design and production

Leads: Dr Daria Cabai (leisure/commercial), Navalmartin Ltd, and Richard Hammond (defence), Naval Ships, BAE Systems

If we are required to prove that we have produced what we designed, how do we test this? We need to ensure that we design in a way that allows NDT to be performed. We need to understand the risks of failure, the risks of not carrying out NDT. However, designs are cost-driven, especially at the low end of the market, so there is no appetite for performing NDT without an associated cost benefit from it. Maybe NDT survey costs could be benchmark-linked to the insurance premium. At present, it is not clear if the cost saving on the insurance premium due to NDT having been performed will outweigh the NDT cost.

There is a question over whether NDT should be mandated throughout life: at manufacture, after a certain mileage (plus distance from a safe haven), etc. This would need to be consolidated across the insurance industry.

Yacht brokers need NDT surveys in order to be allowed to sell yachts. Brokers take a cut from the sale and this is presumably partially used to fund the NDT survey.

Linking NDT to structural integrity

Lead: Professor Janice Barton, University of Southampton

The subtitle of this breakout group was: 'Use of modelling with mechanical test'. One of the first points was that material properties are not well enough known because of all the manufacturing variables. Modelling usefulness will be bounded by this.

NDE is useful for informing the model and setting the geometry of any features/defects and hence the starting conditions. Incorporating NDE outputs as inputs to models would involve an iterative procedure in which models, NDE and stress/strain measurements form a predictive loop and a prognosis on whether the damage will evolve. NDE provides detailed information on defect shape, which allows accurate stress fields to be determined from models of the defects. Live trial data on water would provide good input to structural models, which can be used in conjunction with computational fluid dynamics (CFD) to better understand the influence of the fluid loading on any potential damage progression for different sea states. To do this, a link between testing, NDT and data from structural health monitoring (SHM) sensors must be established.

Why is modelling necessary? To determine design allowables, critical defect sizes, safety factors and to better understand production. For design, obtaining load states from CFD and identifying the critical defect size; to conduct accurate NDE, we need to understand the type and size of the defect that we are assessing.

What else can you use models for other than for structural performance? To design the NDT, modelling ultrasonic/thermal propagation in the materials. But this is a complex problem in composites due to inhomogeneity and anisotropy. This could be more straightforward, particularly for small companies that do not have the resources for extensive testing, if there was a central repository of knowledge on composite materials properties and the application of NDE, maybe held by BINDT. Sharing information and collaborating would help to know which sensor to use and how to set up the sensor system.

It was pointed out that aerospace drivers are very different to those in the marine sector. This kind of modelling would be good for higher end (30+ m) vessels to mitigate risk, but many manufacturers would not do this. Modelling would allow better assessment of defect severity. Decisions will be better informed with improved NDE, but we need to clarify where NDT will save money; the marine sector is conservative and there is a historical acceptance of the status quo that prevents innovation.

Skills and training of inspectors and structural engineers

Lead: Chris Minton, MTD

A recurring theme in this breakout session was a need for understanding the 'product technology' – the materials and structures under inspection. Regarding product technology, it is important to understand the manufacturing process and what you are inspecting, so it is important for the OEM to share the product details with the inspector through a service or inspection manual. This does not happen consistently at present. It is important to properly size and classify whatever defect is found and to know the difference between manufacturing and in-service defects where possible.

Demonstrating the competence of an inspector is more than just certification; experience across a variety of inspections and materials is preferred and knowledge of the product technology is crucial. A suggested way to achieve this is to complete the training and then gain experience on the job before coming back to assess competence. A modular approach to training was put forward, over a number of different courses, with a final assessment at the end. However, the issue of cost was raised; maybe any inspection is better than no inspection at all, which may be the consequence if the expense is too high due to onerous training costs. Who pays for the training?

The question was raised about whether there can be a generic training syllabus for the marine composites industry considering the diversity of materials and structures in use. Where do we start with the new training regime? Who is going to be the first trainer of the trainers? Ideally, an inspector would have good product technology knowledge of marine structures. It was suggested that high-risk areas should be tackled first so that we can build a portfolio of experience in the inspector base.

The importance of keeping a separation between a surveyor and an NDT inspector was discussed, but maybe people are trained to achieve a particular objective rather than training to be a 'surveyor' or an 'NDT inspector'. It was also suggested that NDT familiarisation courses could be marketed/mandated to marine surveyors to increase their understanding of the applications and limitations of the various NDT methods.

Regarding the need for defect characterisation and determining the effect of defects, this is again related to the cost benefit – the value to the owner or insurer of having this information.

Session 6: Panel session

The panel was chaired by Professor Smith and comprised the following presenters from the workshop: Professor John Tyrer, Richard Hammond, Professor Janice Barton, Ken Hickling, Dr Daria Cabai, Chris Minton, Michel Marie and Dr Rachael Tighe. Professor Smith began by asking each panel member to state what they felt was their top priority for NDT to provide to the marine composites industry.

- Professor Tyrer felt it important to focus on the requirement from MAIB: a straightforward demonstration of qualifications and recognition of where qualifications are coming from. We need to address the problem of a lack of regulations resulting in low demand for the qualifications once they have been set up. The presence of such training and qualifications may be welcomed by the community but companies may still not send anyone on the courses; this has been seen before in other sectors. The linkage required is the demonstration of the insurance benefits of certification, such as discounts if the vessel is checked, motivation for the OEM and the owner to use certified inspectors. Professor Smith summarised this as a need for a joined-up approach: we have a mandate to proceed to a qualification but we must discuss how it is implemented, to what it will apply and how to train to the right level, certify and set the right amount of required experience. This is a complicated question. It has taken decades for the aerospace sector to reach the self-consistent and well-regulated position it is in.
- Richard Hammond picked up on a comment from a breakout group that there are essentially no rules governing NDT for composite vessels. There are for steel vessels but not for composites. Part of the reason is a lack of understanding of the NDT analysis and reporting, which does not always give a pass/fail outcome because this needs linking to stress analysis and structural integrity decisions. He put in a request for the NDT community to shout louder, to the right people, about what NDT techniques are available and what they demonstrate (in terms of minimum detectable defect size, etc) and link this into structural integrity to determine what the pass/fail criteria should be. This will allow classification societies to write

rules. Professor Smith commented that this is another 'chicken and egg' problem. People who decide on allowables need to know what we can find with NDT, but we have to know what needs to be found in order to optimise the NDT technique. So there needs to be a dialogue, preferably not over every component but a more generic discussion. Dr Cabai said that the classification societies do not hold the complete solution to the problem. It would be good to have a board or committee of stakeholders involved in order to get input from them. Professor Smith said that we need to define a process concerning how we would do this and who to involve in each case.

- Professor Barton said that the key message is that if the marine industry is to adopt NDT processes, certification and regulations, then money must be saved. If you can say to an organisation that by employing NDT you will save money from the cost of insurance then that would drive the need for NDT. There also has to be an understanding of what we are looking for and why. Technology developers need to show how it helps and saves money.
- Ken Hickling said it does not matter whether at the manufacturing stage, final handover or the in-service stage, the question is the same: 'Is this structure Ok?' As in aerospace, the question is then: 'Do we live with it, fix it or throw it away?' At present, the owner bears the risk, so they go to a perceived expert. This may be an overall surveyor, who may then decide to get an NDT expert in, particularly for a highly stressed carbon composite component. Then the problem arises: who does the surveyor go to and how does he/she know if they are competent? Someone with a boot full of NDT equipment who claims competence *versus* another person with a boot full of different equipment, who also claims competence? How do you tell the difference and determine who is going to be useful to you? What surveyors need is guidance on how to gather the correct information, allowing a decision to be made by the owner or OEM about whether to allow continued usage, repair or scrap. What is needed is guidance that can be used to choose the NDT method, the NDT inspector and the inspection regime. At the moment there is nowhere and nobody to go to for this guidance and advice. Professor Barton agreed that you cannot rely on travelling salesmen. People with expert knowledge are required to provide training programmes, certification and advice. Perhaps BINDT could create a committee of NDT experts and stakeholders?
- Dr Cabai agreed that more guidance is required, especially on what information the NDT methods can provide and preferably a business case about why industry should take up a given solution. Data is key to this. Professor Smith asked Chris Minton to what extent the new certification committee can meet this requirement or whether we need to separate the personnel training and certification from the other requirements that have been identified, which could maybe be taken on by the BINDT Composites Group. Chris Minton responded by saying there are two issues: the legitimacy of the inspectors, countering the perception that they are 'cowboys', and the understanding of the marine structure product technology. Probably 90% of the problem is the latter – NDT inspectors need understanding and experience of the structures and components they are inspecting. Joe Heigold (Chair of the BINDT General Technical Committee (GTC)) said that this is the same in all industry sectors; NDT inspectors coming into an industry without 20 years of experience of that industry need to know all about the product before carrying out NDT. Chris Minton agreed that BINDT recognises this across industries but that for composites materials it is perhaps even more critical.
- Dr Freemantle pointed out that in other industries you have a 'Responsible NDT Level 3' who oversees the NDT practices of the inspectors. So, one way would be to have external Level 3s with oversight of the NDT that is performed. This is the practice in some companies, but in others the Level 3 is in house (as is allowed in aerospace). This allows for a potential conflict of interest to arise, whereas an external Level 3 would be more independent.
- Ken Hickling explained that in the yacht industry, some people will go to someone they know well and regard them as a better source of NDT than any genuine, properly qualified and experienced experts; this gets in the way of any structured approach and is a barrier to the NDT professionalisation from which the industry could benefit. Professor Tyrer suggested that combatting this legacy is not going to be easy; an education process, an awareness campaign, is required to market this to the end-users of NDT, the owners. From the audience a proposal was made for that education process. It needs a tabular approach that can be published to explain the different NDT techniques that are available for different materials, what they do and what defects they can find. There are owners who will employ an NDT inspector with a one inch probe to inspect a 25 m boat because that is what they consider NDT to be. To address this we need to start at the simple end: provide the options and information about what they can be applied to. This is about raising NDT awareness. Dr Cabai said that this needs to be taken up by the association of surveyors, yacht designers, insurers and the regulatory authorities. Sometimes, the surveyors are hiding behind having accreditation of those associations and deciding that NDT surveys are not necessary.
- Michel Marie said that sharing information, knowledge and data relating to both NDT and materials information is really important in order to inform the determination of acceptance criteria. Much knowledge has been gained from experience of NDT at the high end of the NDT market, people have learned themselves, but this is locked into the knowledge of a few experts and is not shared. Land Rover BAR is fortunate because it can close the loop internally for the specific materials and structures used; however, it still relies on outside information. Wider knowledge in the industry has to come from that sharing.
- Dr Tighe said that a top-down approach is required because someone has to foot the bill for bringing in new requirements and technologies. Legislation has to drive it or you are putting your company on an uneven playing field if you are the only company implementing the more reliable methods. Professor Smith agreed that the new regime has to be considered in terms of who is going to pay for it and how it is mandated across the industry, so that companies are not at a disadvantage by taking the decision to use improved NDT.
- Professor Barton had been thinking about what had been said about needing a table or catalogue to show the NDT methods that could be used in a given scenario. There are lots of books and web-based information sources on NDT and NDT techniques, but she believes that it is crucial to know what you are looking for before the information that is available on NDT methods can be boiled down to a guidance document. It will be crucial to draw together the NDT community with the naval architects and the composites community to be able to make an informed decision about what techniques should be used based on the types of vessel that are being inspected.
- Professor Smith suggested emailing this group of workshop attendees to set up a working group that runs alongside the proposed BINDT Composites Certification Committee and is broader than personnel certification but not as broad as the whole

BINDT Composites Group, which covers all sectors. It needs to be a specific Marine Composites Inspection Group, including naval architects, manufacturers and end-users, as well as NDT experts. The objectives will cover the generation of guidance and information on the use of NDT for marine composites, how to implement it and the benefits that NDT can offer, and will recommend a regime for mandated regulation.

- Pete Burrows advised that the oil industry has an interactive knowledge base (IKB) that recommends NDT techniques and defects and advises on their pros and cons and what the options are for a particular structure. Professor Smith said this may be the same NDT Selection Tool IKB that he assisted in developing with government funding about 11 years ago, in collaboration with ESR Technology, which runs the HOIS offshore group, and NetComposites. The IKB is accessible via the NetComposites website but it is 11 years out of date now (https://netcomposites.com/news/2007/april/10/netcomposites-launches-ndt-selection-tool). The BINDT Composites Group is aware of this and could consider bringing it up to date. However, this is always the danger of documenting capabilities at a point in time when there is no funding for regular updating of the documentation; you could put in place a barrier to new technology.
- John Tyrer said the challenge is that, while we can scope out all of these things that we need to do, there is no budget and there is not going to be one. We are trying to respond to a MAIB requirement that could be made legislative if we do not respond appropriately. This means that we cannot afford to start on a massive programme to develop a full interactive solution. We need to work with people from the industry who know the structures and develop a simple and straightforward guidance at a high level but with the potential to develop it with more detail later.
- Professor Smith agreed this would be a quick win but this workshop is aimed at defining the requirements so that funding can be sought. He asked whether there is an Innovate UK equivalent for the marine industry of the Aerospace Technology Institute (ATI) or the Advanced Propulsion Centre (APC) for the automotive industry. There is a Shipbuilders and Shiprepairers Association (SSA), but it only has 26 members. The British Marine Federation (BMF) has over 1600 members so might be appropriate, but it is a trade association and does not channel government funding like ATI and APC. (Note: The UK Marine Industries Alliance was funded by Innovate UK to produce the 'UK Marine Industries Technology Roadmap 2015', which mentions a composites NDE process as a technical capability objective, under Structures and Materials, for 2018-2020.)

Conclusions and recommendations

The following requirements were identified during the workshop and proposed actions to meet those requirements are included when offered and where appropriate:

1. A link should be established between the BINDT Composites Group and the Technology and Innovations Group of the UK Marine Industries Alliance, membership of which includes: Innovate UK, BIS, KTN and EPSRC. It is also the UK National Contact Point for Marine for the European Framework Programme.
2. A Marine Composites Inspection Group of the BINDT Composites Group should be created to focus on delivering the requirements of this workshop and report. It needs to include naval architects, manufacturers and end-users, as well as NDT experts. The objectives will cover the generation of guidance and information on the use of NDT for marine composites, how to implement it and the benefits that NDT can offer. It will recommend a regime for mandated regulation. A link with ISO Technical Committee 8 – Ships and Marine Technology, Sub-Committee 12, should be established to ensure consistency with international standards.
3. A BINDT Composites Certification Committee should be formed within BINDT to cover the personnel training and certification aspects of the requirements, reporting initially to the BINDT Composites Group, but also working with the BINDT General Technical Committee (GTC). This committee will focus on the marine composites requirement first, especially the issue of ensuring adequate understanding and experience of the wide range of marine composite product technology.
4. The Marine Accident Investigation Board (MAIB) has stipulated that NDT inspections of composite structures should be undertaken by inspectors who have been specifically trained and qualified according to a recognised NDT personnel certification scheme. The primary objective of the above BINDT Composites Certification Committee is to meet this requirement in a timely manner, in consultation with MAIB and the Maritime and Coastguard Agency (MCA).
5. Combatting the legacy and inertia in the marine industry is going to be challenging; an education process or awareness campaign is required to market this to the end-users of NDT, the owners, so that they demand a higher level of expertise and information. NDT familiarisation courses could be marketed/mandated to marine surveyors to increase understanding of the applications and limitations of the various NDT methods. Perhaps NDT survey costs could be benchmark-linked to the insurance premium so that the cost saving on the insurance premium due to NDT being performed by qualified NDT inspectors will outweigh the NDT cost.
6. It is important that there is a top-down legislative requirement driving the need for personnel certification in composites NDT. Such regulations could be enforced if the OEM was required to provide something more than the current warranty: guaranteeing over longer periods by inspection. Risk of prosecution would be a significant and crucial driver, possibly involving the HSE, for example. This could cover in-service NDT as well as NDT at manufacture. While regulation defines how things should be done correctly, it is the risk of prosecution or other consequences of not following regulations or procedures that act as drivers to conform. The new BINDT Composites Certification Committee should work with MAIB and MCA to establish how this will be enforced and on what timeline, in order to ensure that BINDT's investment, and that of training organisations, in this certification scheme is justifiable from a business perspective and will actually meet the objectives of MAIB and MCA.
7. The link between defects and their effect on structural integrity is currently extremely weak for marine composites. This is partly due to a lack of information from the NDT process but also due to the lack of a joined-up approach linking NDT findings to stress analysis and disposition decision-making by designers. An increased use of mechanical modelling of defective structures could greatly increase the understanding about the effect of defects and help to determine defect allowables, or even be used directly to determine the residual strength of a damaged component. In order to achieve this, the NDT community needs to work with the designers, naval architects, insurers and end-users (owners) to define and recommend or mandate a process.

8. A high-level NDT best practice guidance document should be developed by the new BINDT Marine Composites Inspection Group linking material type, component type and defect type to applicable NDT methods, their capabilities and limitations. If there is any value in linking to existing knowledge bases, standards or publications, then these should be referenced. Funding sources such as Innovate UK should be explored for funding this development, with the potential for linking it to regulations or making it a surveying best practice guide.
9. It is important that marine designers, insurers and surveyors fully understand the importance of high-quality inspections and the risks of failure to detect defects. This is about raising NDT awareness and needs to be taken up by the associations of surveyors, yacht designers, insurers and the regulatory authorities.
10. There should be a guidance document and training available on the structural integrity of generic marine composite components (products) so that NDT inspectors can be trained to understand the components they are inspecting.
11. A central information-sharing repository should be established by the new BINDT Marine Composites Inspection Group and made available online for material properties, structural integrity information and NDT information and experiences, possibly held by BINDT. This will help with linking detected defects to their effects on structural integrity, including the use of modelling.
12. Funding should be sought to develop the above best practice document and the information-sharing repository, as well as the legislation and future interactive knowledge base. UK Marine Industries Alliance, whose membership includes Innovate UK, BIS and the KTN, would be a good place to start. Maybe BINDT could lead a bid into Innovate UK?

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Appendix A: Delegate list

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Oliver Blume	Hydraulics Consulting
Darren Boakes	Resolution NDT Ltd
John Bond	Olympus
Patrick Boulton	BINDT
Stephen Boyd	University of Southampton
Harry Britton	Sonatest Ltd
Pete Burrows	Baugh & Weedon Ltd
Daria Cabai	Navalmartin Ltd
Gath Cheyne	Baugh & Weedon Ltd
Richard Craven	QinetiQ
Daniel Crockford	Keoghs LLP
Ed Danby	Marine Results International Ltd
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Karl Davis	MS Amlin
David Deeney	Sonatest Ltd
Kate Devereux	University of Southampton
James Downing	Babcock International
Phil Edwards	Testia Ltd
Andy Elford	Marine Concepts Ltd
Cailean Forrester	Inspectahire
Richard Freemantle	Wavelength NDT
Nikita Gandhi	National Composites Centre (NCC)
Torsten Goericke	Zucker & Partner
Arne Gvlzow	Carbo-Link AG
Graham Haines	Cygnus Instruments Ltd
Robin Hallett	BAE Systems – Maritime Services
Richard Hammond	BAE Systems
Neil Harrap	TWI Ltd
Tristan Harwood	Bartons Solicitors
Joe Heigold	Skills Training UK Ltd
Ken Hickling	ICOMIA
Hasso Hoffmeister	DNV GL
David Jonson	Land Rover BAR
Dave Lines	Diagnostic Sonar Ltd
Charlotte Lovett	Hiscox MGA
Michel Marie	Land Rover BAR (now INEOS Team UK)
Graham McCully	Applus Aerospace UK Ltd
Chris Minton	Minton, Treharne & Davies (MTD)
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James Pitman	BAE Systems Maritime Services
David Rees	Pierrepont Analysis Ltd
John Rudlin	TWI Ltd
Helen Rudorf-Saeed	ZIS Ltd
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Christopher Simmonds	Ultramag Inspection Services
Cameron Sinclair	BINDT
Chris Smith	RNLI
Robert Smith	University of Bristol
Linda Starink	Lloyd's Register
Joe Summers	AEL Airborne
Jonathan Sutcliffe	JME Ltd
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Rachael Tighe	Defence Academy of the UK
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