Publishable JRP Summary Report for ENG57 VITCEA
Validated inspection techniques for composites in energy applications

Background

The excellent mechanical properties, low weight, fatigue and corrosion resistance of fibre reinforced plastic (FRP) composites gives them considerable advantages in renewable energy (wind, wave and tidal), oil and gas, and transport applications. The use of FRP composites has the potential to reduce fossil fuel reliance, consumption and greenhouse gas emissions. However, full exploitation is hindered by the diverse range of defects and damage mechanisms that reduce the strength, stiffness and life of FRP structures. Non-destructive evaluation (NDE) is the process used to ensure material quality (e.g. maximum defect size) of a component and that parts are fit for purpose.

Need for the project

There is a need for a range of validated NDE techniques with contrasting detection capabilities for the identification and sizing of defects that directly impact component performance and working life of FRP composites. This will also enable integration of novel NDE techniques at an earlier stage of production, allowing improved design, manufacturing and assembly with inspection being facilitated throughout the life cycle, not only in-service. Furthermore, defect detection capability has a major influence on the service intervals for FRP composite energy assets. Defects in FRP structures may be introduced during the processing and fabrication of composite components and can initiate or grow in-service. In the context of this project, the term 'defect' refers to imperfections introduced during manufacture/processing and/or secondary machining operations, as well as damage sustained during a component's service life. One of the challenges facing accurate and repeatable defect detection in FRP composites is the multitude of defect types that exist, each with characteristics that present different challenges to the NDE practitioner. In order for a particular NDE technique to achieve broad acceptance by industry, it is desirable for the technique to be able to detect a range of defect types with a high level of confidence.

Despite many innovations in the development of NDE for the assessment of defects and damage, relatively few methods are commonly used. This is mainly due to the fact that standardised operational procedures are not available and perceptions that NDE is too unproven, costly or complex. There are currently no ISO NDE standards in existence that are specific to defect detection in composites. Several ASTM composite NDE specific standards are available, but these tend to be focussed on the aerospace sector and do not provide enough detail and validated data addressing issues such as probability of detection (POD), defect size and location sensitivity. The need exists to realise promising novel NDE techniques such as microwave, active thermography, laser shearography and phased array/air-coupled ultrasonics, thus enabling the increased use of FRPs for energy applications.

Scientific and technical objectives

The work proposed in this project will develop and validate traceable procedures for novel NDE techniques with contrasting detection capabilities, which will underpin the increased use of FRP composites for improved efficiency and reliability in energy related applications e.g. wind and marine turbine blades, nacelles, oil and gas flexible risers. The specific objectives are:

- To design and manufacture suitable natural and artificial reference defect artefacts representative of the materials and defects typically found in, and of concern to, the renewable energy (wind, wave, and tidal), oil and gas and transport sectors;
- To develop operational procedures, drafted in the style of CEN and ISO standards, for: microwave; active thermography; laser shearography, and phased array ultrasonic techniques. The metrology objectives are to:

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i) Establish the limits of detection for each NDE technique;

ii) Develop analytical techniques for accurately sizing defects for the different NDE techniques. The NDE results will be compared with independent characterisation techniques;

iii) Compare the merits of each NDE technique for different defect types found in a broad range of composite material systems using an objective POD benchmarking framework;

iv) Advance the theoretical simulation of the inspection techniques in particular taking into account the intrinsic anisotropic nature of composites and their constituents;

- To evaluate the POD methodology, based on modelling simulations with the aim of reducing the cost and time requirements of intensive experimental POD trials;
- To validate and refine operational procedures via intercomparison exercises and field trials in collaboration with organisations from the renewable energy (wind, wave and tidal), oil and gas and transport sector supply chains. Defect artefacts will be inspected using the developed operational procedures.

Expected results and potential impact

Design and manufacture suitable natural and artificial reference defect artefacts

During the initial stages of the project an industrial survey was undertaken by NPL in consultation with BAM, PTB, CMI and REG(CEA) that established the material systems, components/structural elements and defect types (including size and location) that are most routinely required to be inspected, and those that present significant challenges to NDE inspection. The outcome of this survey resulted in a total of 13 designs for reference defect artefacts (RDAs) and natural defect artefacts (NDAs) covering marine and automotive transport, renewable energy and oil and gas sector applications. RDAs and NDAs were designed and manufactured as a joint effort by NPL and BAM, with input and discussion from other partners. These builds were all finally completed during 2015, and the items circulated to all JRP members for further characterisation and assessment.

The material choices reflect the specific industry sectors targeted by the project and the defect types chosen reflect the key concerns of industry. Defects created reflect issues in material consistency, processing-related issues, and damage that may be encountered in service. The range of materials employed include composites based on thermoset and thermoplastic matrix systems reinforced with glass and carbon unidirectional and multi-directional tape and fabric formats. The elastic, dielectric, thermal and optical properties for each material used in the RDA and NDA designs were characterised by all partners. Dielectric data measured at 10.5 GHz has been generated for all GFRP materials and used to project the real part of the complex permittivity at 24 and 34 GHz.

In addition to the RDAs and NDAs, NPL, BAM and REG(CEA) designed and manufactured two additional RDAs specifically for use in the probability of detection (POD) and intercomparison exercises. These POD-RDAs, were made from CFRP (carbon fibre-reinforced plastic) and GFRP (glass fibre-reinforced plastic) materials and feature 13 different sizes of artificial delaminations and back-face drilled holes, with diameters ranging from 1 mm to 40 mm.

Development of operational procedures for microwave, active thermography, laser shearography and phased array ultrasonic techniques

The RDAs and NDAs have been used to evaluate the detection limits and sizing capabilities of phased array and air-coupled ultrasonic, laser shearography, microwave and active thermography NDE methods. The defect types included: delamination, porosity, kissing bonds, fibre misalignment, pipe wall thinning (back-face drilled holes), core damage, impact delaminations and matrix cracking. Currently, operational procedures produced for each NDE technique are being evaluated via a series of POD assessments and intercomparison exercises.

For each of the materials used in the construction of the RDAs, NDAs and POD-RDAs, material property data (elastic, dielectric (excluding CFRP), optical and thermal) have been measured to enable the optimised practical application of phased array and active thermography techniques, and the theoretical simulation of NDE techniques.

In the microwave area, modelling development activity has focussed on the application of electromagnetic modelling techniques to simulate microwave inspection of FRP composites. The results have been very encouraging with excellent agreement between simulated and experimental results achieved. The simulations have also indicated the presence of lateral standing waves within the material at small index increments, showing up as striations on the experimental scans, as well as the formation of standing waves between the waveguide and RDA surface. Additional modelling work has resulted in REG(CEA) modifying their CIVA ultrasonic software to take into account the true profile of delamination in curved laminates, whilst in the thermography area, BAM has developed the numerical models of anisotropic heat diffusion for active thermography including flash heating, step heating and lock-in excitation of the artificial defects. Numerical solutions were validated using the experimental results.

Evaluation of the POD methodology based on modelling simulations

An experimental and theoretical POD assessment approach that is being employed for all NDE techniques has been developed by REG(CEA) and NPL. The approach is based on the signal response for each technique and requires at least 40 data points to be measured for the generation of POD curves. The outcome of the POD modelling simulation work will determine whether modelling can effectively be employed to reduce cost and time requirements for intensive experimental POD trials.

Validation and refinement of operational procedures via intercomparison exercises and field trials

A detailed schedule has been put in place for the intercomparison exercises and a list of participating stakeholders has been compiled which is currently running in parallel with the POD assessment exercise. The Stakeholders are split across equipment suppliers, end users and academia within Europe. The outcome of the intercomparison exercises and field trials will allow further validation and refinement of the developed operational procedures which have been completed in draft form.

Impact

Impact activity highlights to date include invited representation on the Composites Group committee of the British Institute of Non-Destructive Testing (BINDT), the General Technical Committee for Composites of the BINDT and the Millimetre-wave and THz Users Group (BINDT) and attendance at an industrial engagement meeting of the UK National Composites Centre's NDE Defect Library initiative. The optimised NDE techniques, operational procedures and modelling capability developed by the partners, in collaboration with industrial collaborators, will lead to improvements in safety, life expectancy, energy efficiency and sustainability; and reductions in fossil fuel reliance, greenhouse gas emissions and maintenance costs for FRP assets in the energy sector.

Project-related presentations were made at the 19th WCNDT 1026 in Munich in June 2016 (four oral presentations and one poster) and at the ECCM17 (17th European Conference on Composite Materials: 26-30th June 2016 (Munich, Germany) (one oral presentation). The WCNDT presentations have proceedings published online (http://www.ndt.net/wcndt2016)

Eight scientific journal publications are currently in preparation stages and will be submitted in the next 6 months. NPL published an article in a trade journal (Adjacent Government) during August 2016. The article highlighted the VITCEA project aims and was entitled: "*Validated Inspection Techniques for Composites in Energy Applications"*

The VITCEA project has developed a plan to ensure that the outputs of the project are exploited to the benefit of the asset owners, end-users, designers and NDE communities involved with the use of FRPs in energy applications in the renewable, oil and gas and lightweight transport sectors. The key project outputs that will be exploited will include:

- Reference materials, sector specific RDAs, NDAs and POD-RDAs, including design and production methodologies that will be made freely available after project completion.
- Validated operational procedures for ultrasonic (phased array, air-coupled), microwave, active thermography, and laser shearography techniques.
- Additional measurement services from the creation of new methods for measurement of thermal and optical properties.
- On-site and in-field NDE consultancy through the development of operational procedures for ultrasonic (phased array, air-coupled), microwave, active thermography and laser shearography techniques.

- Development of new modelling capability for ultrasonic phased array, microwave and active thermography, enabling theoretical POD assessments to be undertaken.

JRP start date and duration:	1st July 2014, 36 months
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