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INTEGRATED ASSESSMENT OF COMPOSITE TO STEEL JOINTS IN MARINE APPLICATIONS

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ABSTRACT

Implementation of bonded joints in structural marine applications has proven challenging as there is no widely accepted method of assessing the integrity of such joints. In particular, a framework for assessing the effect and criticality of damage is not available. Therefore, an approach is presented where the effect of defect type, size and location can be predicted using a high fidelity Finite Element Analysis (FEA) model. A method for the validation the numerical model is proposed that uses full field imaging techniques. The validation procedure is developed initially using the well understood single lap joints. Both Glass Fibre Reinforced Polymer (GFRP) and hybrid GFRP -steel joints are considered. These are subjected to tensile loading and high resolution Digital Image Correlation (DIC) is used to obtain full field strain data in the through thickness direction. Pulse Thermography (PT) is used to inspect the joints for damage post manufacturing and under load. The paper present preliminary experimental and numerical work carried out single lap joints.

1 INTRODUCTION

Incorporating composite structures into naval ships, offers advantages such as increasing vessel stability, by lowering vessel centre of gravity, and enabling the integration of multiple functions, e.g. structural and radar signature reduction. Attaching composites superstructures to a deck usually necessitates a composite to steel joint. To reap the benefits of such structures, it is desirable that the connection between the composite superstructure and steel vessel substructure be made by adhesive bonding. Currently mechanical fasteners are used, but this adds to the part count, weight, and requires drilling of the laminate. Hence, is not desirable and alternatives are being investigated. Bonded joints, overcome these limitations, and have been implemented on a small number of vessels such as the La Fayette class frigates of the French Navy [1]. However, uptake of similar bonded joints has been limited. A key concern is that it is difficult to prove the integrity of such hybrid bonded joints. Joint defects or damage can occur during manufacturing or in-service, significantly reducing joint strength and stiffness. Defect identification is hindered by the complex geometry and combination of differing materials within the joint. However, vessel operators face a potentially greater challenge once defects are identified. Currently there is no accepted framework to assess how defects affect residual joint strength and service life. An ongoing project [2] aims to conduct data rich studies to provide high fidelity evaluation of large structures. As part of this project, the present work aims to develop a framework for the assessment of defect criticality, to be used to prove structural integrity of joints. The method integrates a detailed numerical model with validation testing. The modelling space is then used to assess joint strength, damage propagation and residual service life.

2 JOINT CONFIGURATION

The joint configuration used in the La Fayette class joint (LFJ) is shown in Fig. 1. The LFJ features a composite sandwich structure which tapers in thickness. GFRP is laid up covering the balsa wood and steel forming a single structure. The free end of the steel is then welded to the steel structure of the vessel.

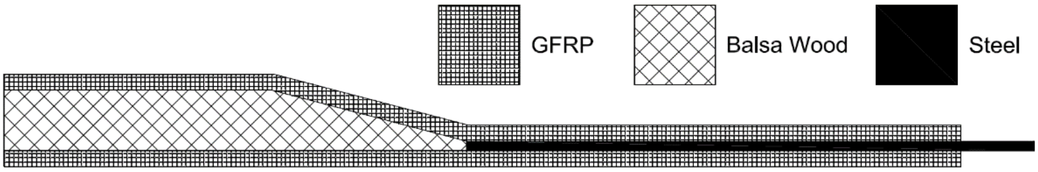

Figure 1: La Fayette joint configuration

Although different in configuration, the LFJ shares a likeness to Single Lap Joints (SLJs) from joint mechanics perspective. Both exhibit load eccentricity, leading to high transverse normal (peel) stresses, which, in combination with shear stresses, lead to failure. Therefore, in the present paper the development of the integrated assessment method initially focuses on the well-understood SLJ, which can be extended to the LFJ in future work.

3 DEFECT INDENTIFICATION

Post manufacture, it is possible that defects are present in the SLJ bonds. It is important that these are identified and quantified as they affect results and model validation. PT was used by Tighe *et al.* [3] to identify defects in SLJs of thin carbon fibre laminates. Recently, Ólafsson *et al.* [4] improved the approach to PT to make it applicable to thicker GFRP laminates by implementing novel processing routines. The significant improvement in defect identification shown in Fig. 2 has allowed PT to be used to rapidly and non-destructively identify pre-existing damage in the present study.

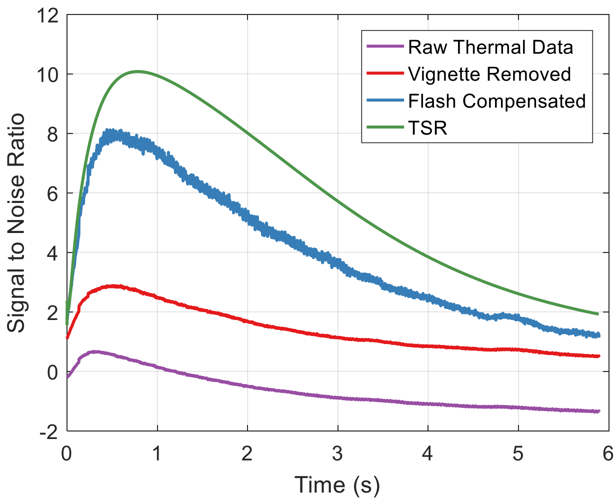

Figure 1: Processing PT inspection data [4]

4 MATERIALS AND METHODOLOGY

Two types of SLJ specimens were manufactured, one GFRP to GFRP and the other GFRP to steel shown in Figure 2 a) and b) respectively. Assuming joints are well-designed and manufactured, SLJs are known to fail in the adhesive at the adherend ends as transverse normal tensile stresses exceed the tensile strength of the adhesive. This region of peak strain was therefore of interest, and in this case is used in the model validation. However, when identical adherents are used, failure can occur at either end of the overlap region. Therefore, the specimens were designed with substrates of differing bending rigidity thus ensuring failure occurred at a known location. The material properties were sufficient to ensure a significant difference in bending rigidity in the steel to GFRP joints, while the GFRP to GFRP joints were manufactured using two different adherend thicknesses (0.6 and 1.2 mm) to achieve the same effect.

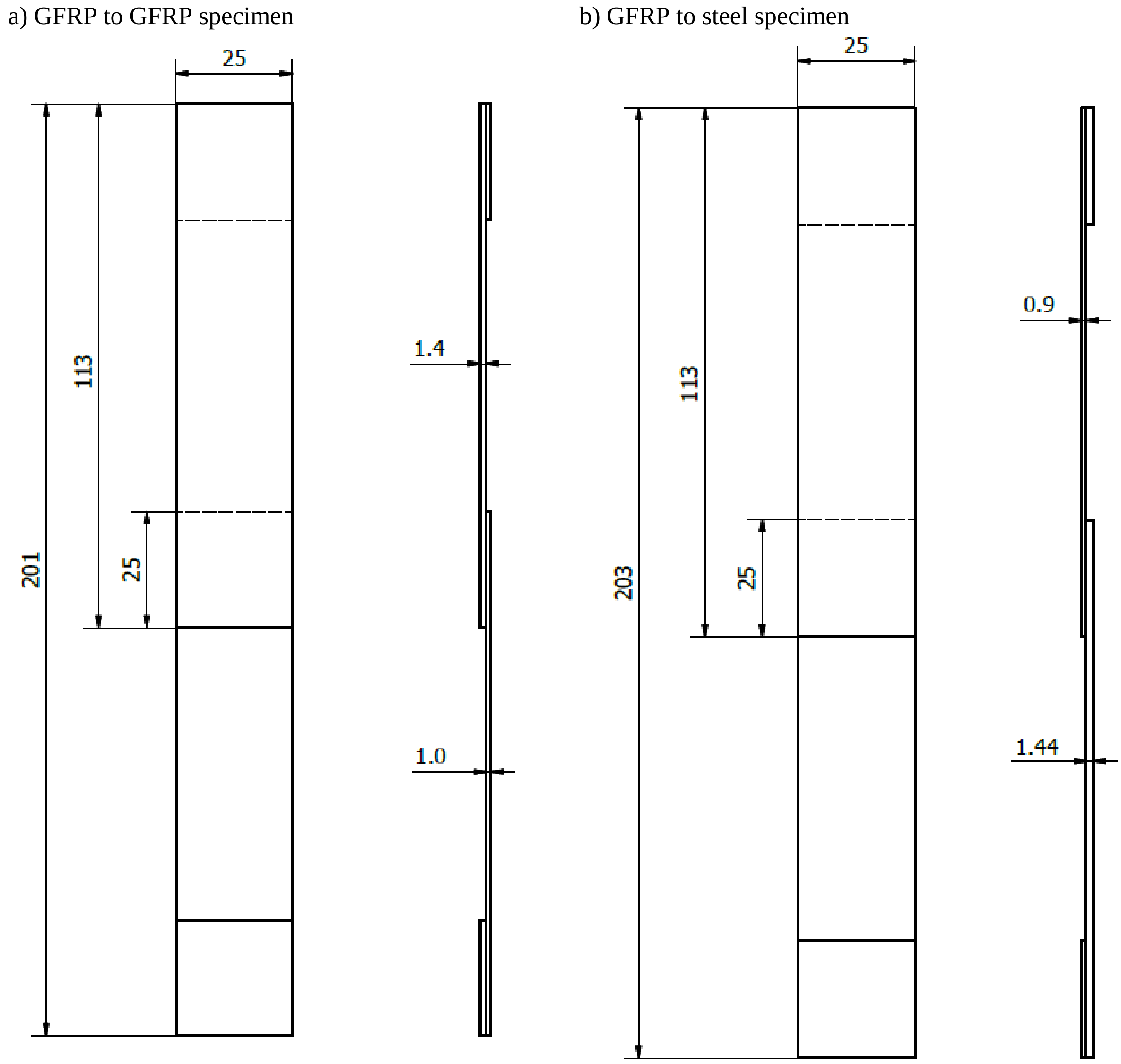

Figure 2: Single lap joint geometry

Two full field imaging techniques were used as shown in Figure 3, with white light cameras for DIC, and a photon detector which was used for PT. The fields of view chosen for white light and thermal imaging were perpendicular to each other such that data acquisition could be carried out simultaneously. For DIC, two 16MP LaVision Imager Lx high resolution cameras were used. These were placed either side of the specimens to ensure failure was captured in the DIC data, and so that an estimate of out of plane deformation could be made. Two Canon MP-E 65 mm lenses were used at x5 magnification. The speckles patterns were applied using an airbrush, to achieve the required speckle size control. A Telops FAST-IR photon detector and a Bowens Pro 1000 photographic flash were used for all PT inspections. Specimens were quasi-statically loaded in tension at four load steps (0.5, 0.8, 1.0, 1.5 kN), at each step DIC and PT data were captured. The specimens were subsequently re-tested to failure with DIC and force extension data captured for each specimen.

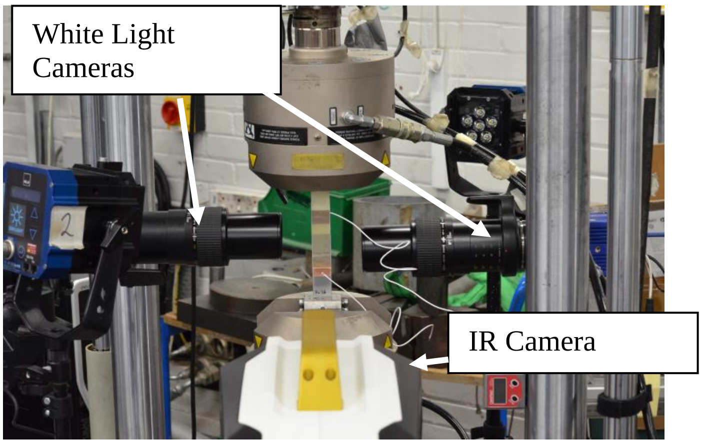

Figure 3: Experimental setup showing white light and thermal cameras

All numerical modeling was performed in Abaqus 6.14.3, using three dimensional models. The adherends were modelled using linear elastic elements as the adhesive was expected to fail prior to plasticity onset in the adherends. The adhesive layer was simulated using an exponential Drucker-Prager model, with values obtained from [5]. To compare FEA data to DIC, nodal displacements and strains were exported from the model from a region comparable to the DIC field of view. These were then imported into Matlab R2016a along with DIC displacements and strains. Interpolation of the data using the *griddata* function within Matlab was necessary to obtain data at common coordinates such that a direct comparison to be made between the two data sets.

5 PRELIMINARY RESULTS

The full field strain map obtained from DIC is shown in Figure 4 a) from test of a GFRP to steel joint. As expected the peak strains occur at the adherend ends, while there is low strain in this direction in the rest of the adhesive and adherends. Figure 4 b) shows the shear strain in the joint is carried in the adhesive, reducing to zero at the free surface and the interfaces between adhesive and adherends. Overall, this corresponds well with the numerical model data shown in Figure 5, however the peak strain shown in Figure 4 a) are concentrated at the spew fillet, which is not currently captured in the numerical model.

a) Transverse normal strain (ε_{xx})　　b) Shear strain (ε_{xy})

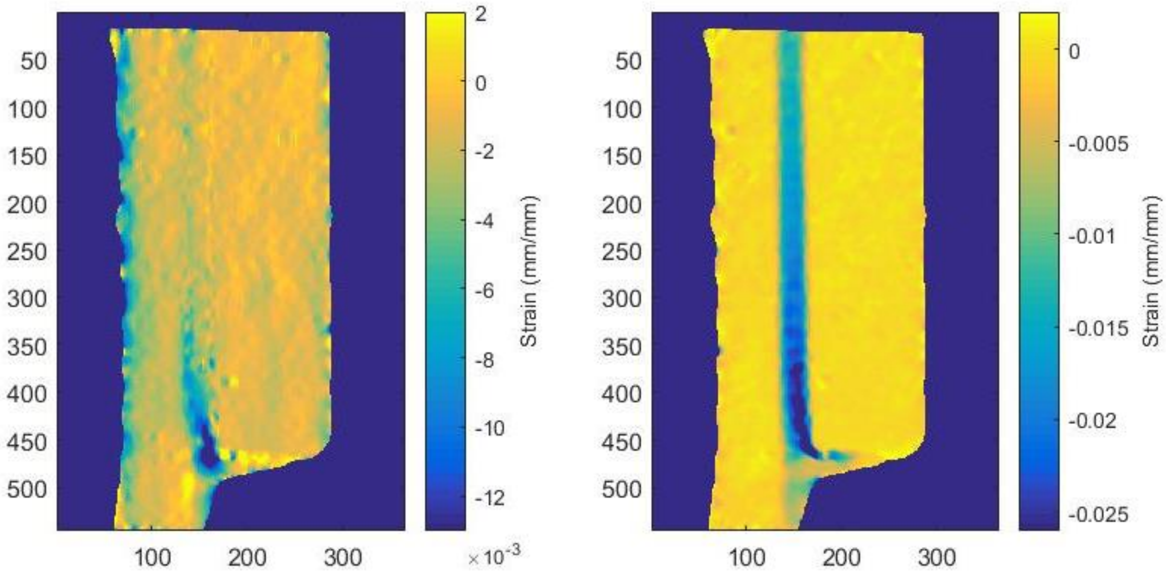

Figure 4: GFRP to steel single lap joint DIC strain maps at 0.5 kN tensile loading

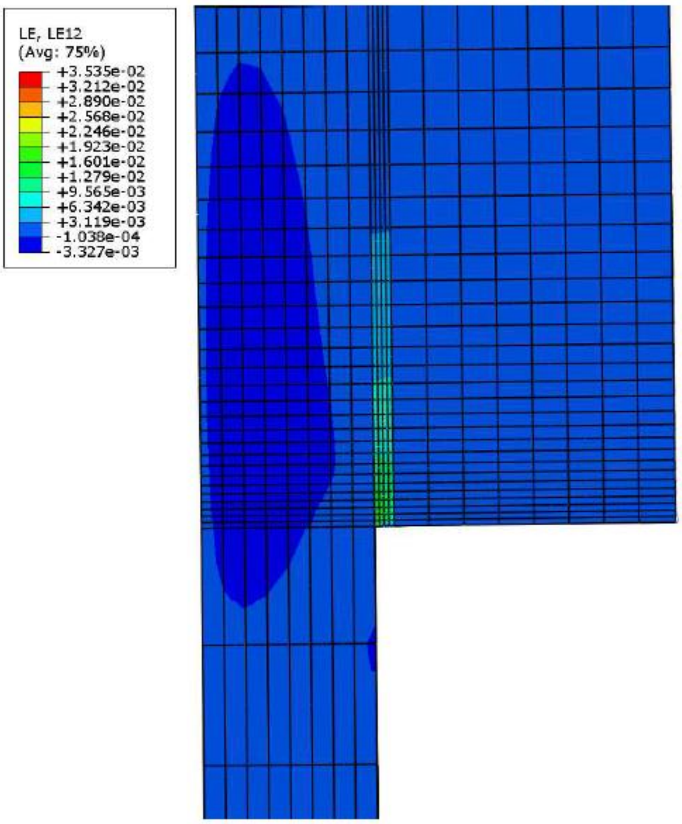

Figure 5: FEA data showing shear strain for a GFRP to steel SLJ at 0.5 kN tensile loading

6 CONCLUSIONS

A method has been developed that exploits advances in full field imaging techniques to validate a numerical model of a single lap joint. Future work will apply this methodology to more complex joints that better represent joints currently implemented ships and those to be used on future vessels.

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