155 An Integrated Methodology Evaluating the Integrity of Composite to Steel Joints for Maritime Applications

G. Ólafsson[1a], R. C. Tighe[2] and J.M. Dulieu-Barton[1]

[1]Faculty of Engineering and Physical Sciences, University Road, University of Southampton, UK, [2] Faculty of Science and Engineering, University of Waikato, Hamilton 3240, New Zealand

[a]g.olafsson@soton.ac.uk

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. Currently mechanical fasteners are used, but this adds to the part count, weight, and requires drilling of the laminate. Hence these are 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 material properties 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 current 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.

Joint Configuration and Analysis

The joint configuration used in the La Fayette class joint (FLJ) is shown in Fig. 1. The LFJ features a composite sandwich structure which tapers in thickness. Glass fibre reinforced polymer (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.

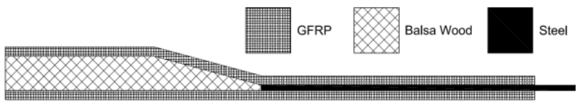

Figure 1: La Fayette joint configuration

Although different in configuration, the LFJ shares a likenesses to Single Lap Joints (SLJs) from joint mechanics perspective. Both exhibit load eccentricity, leading to high 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, before being extended to the LFJ.

Defect Identification

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. Pulse Thermography (PT) was used by Tighe *et al.* [3] to identify defects in SLJs of thin carbon fibre laminates. Recently, Ólafsson *et al*. [4] expanded the method to thicker GFRP laminates using a novel processing routine. The significant improvement in defect identification shown in Fig. 2 allows PT to be used in the present study to rapidly and non-destructively identify pre-existing damage, and damage accumulation during testing.

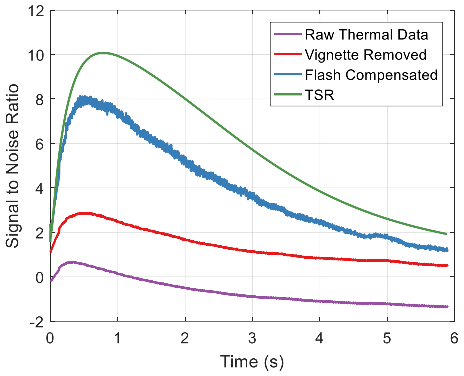

Figure 1: Processing PT inspection data [4]

Numerical Model and Validation

A numerical model was created using the Finite Element Analysis (FEA) package Abaqus to assess the stress distribution in a SLJ during quasi static loading. The model parameters used are provided in Table 1, with results shown in Fig. 3 in comparison to Goland Reisnner analysis [5]. Stresses were taken within the adhesive, at the interface between adhesive and substrate, ensuring peak stresses are captured. The numerical model was validated by comparing peel strain distribution from FEA to strains obtained experimentally using Digital Image Correlation (DIC) in a procedure demonstrated in [6].

Table 1: SLJ modelling parameters

Joint Width	25 mm
Overlap	25 mm
Adherends	GFRP
Adherend Thickness	2 mm
Adhesive	Epoxy
Adhesive thickness	0.5 mm
Force applied	2.4 kN Tension

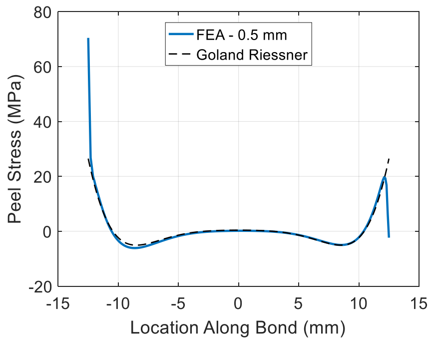

Figure 2: Transverse normal stresses along bond line

Investigation of Damage Progression

To prove joint integrity it is also necessary to validate predicted damage progression. Cohesive zones are added to the FEA model to predict damage onset and propagation. The model is experimentally validated by cyclically loaded the SLJ to initiate and propagate damage. DIC is used to validate FEA strain fields and Thermoelastic Stress Analysis (TSA) is used monitor the rate of damage propagation, with a field of view across the width of the specimen.

Conclusions

The work presented describes how the methodology developed during the investigation of a SLJ can be used to develop a high fidelity joint model that can be used for both design purposes and to assess joint integrity after in-service damage. Proving joint integrity is currently a key barrier to further use of composite materials in marine applications. This work therefore takes an important first step in the development of a frame work that enables increased use of bonded joints used in maritime applications.

References

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