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Effect of sea environment on interfacial delamination behavior of polymeric sandwich structures

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Sandwich structures are utilized in naval craft and thereby are exposed to sea water environment and temperature fluctuations over extended periods. The sandwich layup consists of a closed cell polymeric foam layer placed between thin carbon or glass fiber reinforced polymeric composite facings. Attention in this paper is focused on sea water effects on the interfacial mechanical response between foam and facing due to sustained sea water exposure using carefully controlled laboratory conditions. Pre-cracked sandwich composite samples are soaked in sea water for extended periods and interfacial fracture behavior compared against dry specimens. Results indicate that the delamination crack propagates close to the interface in the wet case, while it stays within the foam in the dry case. Significant reduction in fracture toughness due to sea water exposure is observed and needs to be considered in the design of ship structures. The effect of sea water on values of energy release rate are determined experimentally and predicted using the *J*-integral concept. A good agreement between data and predictions is achieved, indicating a reduction in fracture toughness by 30% due to sustained exposure to sea water.

1. Introduction

This article is part of a research effort aiming at the evaluation of the effects of sea water on the deformation, damage, and material properties of sandwich structures and closed cell polymeric foams. The effects of sea water environment on the mechanical properties of H100 foam and carbon fiber composite facings, and the sandwich structure are being evaluated as a part of the ongoing research sponsored by the United States Office of Naval Research (ONR). The experiments to date involved generation of sea water sorption and permeability data, determination of expansional and diffusion coefficients, as well as the measurement of wet and dry interfacial debond fracture energies and sea water induced property degradations. This paper reports the results associated with the effect of sea water on the delamination behavior of sandwich structures.

It was established in previous works [1–3] that most of the sorbed water in closed cell polymeric foams remains confined to a boundary layer adjacent to the exposed surfaces. This water causes volumetric expansion in the foam and enhances the growth of delaminations at the foam/carbon fiber-facing interface, reducing the resistance to that form of fracture. It was also noted that a secondary mechanism of water ingress is provided by the foam's permeability, adding about 4% to the relative weight gain throughout the interior region of the immersed foam. Both components of the absorbed sea water were accounted for in the sequel.

It is well known that, in the absence of special provisions, cracks in foam cored sandwich specimens do not propagate in a self-similar manner, but often kink up or down. The direction of kinking was determined in the past from the mode mixity associated with the mechanism at hand. Crack kinking analysis has been reported in the past [1,4,5].

The critical values of wet and dry interfacial fracture toughness were evaluated by the same method employed by earlier investigators [1], except that some novel refinements were incorporated herein to detect crack length and its morphology, and present computations are based on recently recorded material data [3]. The foregoing fracture data were calibrated by means of laminate analysis to enable the performance of comparative computational evaluations. These computations employed the finite element method (FEM) to determine the levels of fracture toughness by means of the *J*-integral [6].

Both scatter and average values of the experimental data agreed remarkably well with the computational predictions.

2. Materials and experimental set-up

2.1. Sandwich panel

The composite sandwich panels of size 60 × 90 cm (2 × 3 ft) and 2.54 cm (1.0 in) thickness were fabricated using the VARTM

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process [7]. The facing material was made of carbon stitch bonded fabric designated by LT650- C10-R2VE supplied by the Devold AMT AS, Sweden. This was an equibiaxial fabric produced using Toray's Torayca T700 12k carbon fiber tow with a vinyl ester compatible sizing. The weight of the fabric was 634 g/m^2 with 315 g/m^2 of fiber in the 0° direction and 305 g/m^2 in the 90° direction. Both directional fibers were stitched with a 14 g/m^2 polyester knitting thread. Toray's Torayca T700 carbon fiber was chosen because of its lower cost and higher strength. The T700 fiber had a tensile strength of 4.9 GPa (711 ksi), a tensile modulus of 230 GPa (33.4 Msi), and an elongation of 2.1%. The matrix used was Dow Chemical's DERAKANE 510A-40, a brominated vinyl ester, formulated for the VARTM process. The bromination imparts a fire-resistant property to the composite. The fiber volume was found to be 58% by the area density method and includes 2.2% weight of polyester stitch fiber. The core material was H100 Divynicel PVC foam having an average density of 100 kg/m^3 and average cell size of 0.15 mm.

2.2. Specimen preparation and conditioning

The above mentioned panels were cut and machined to form 254 mm long, 25.4 mm wide, and approximately 29 mm high sandwich specimens. In addition to the foam and facings, the

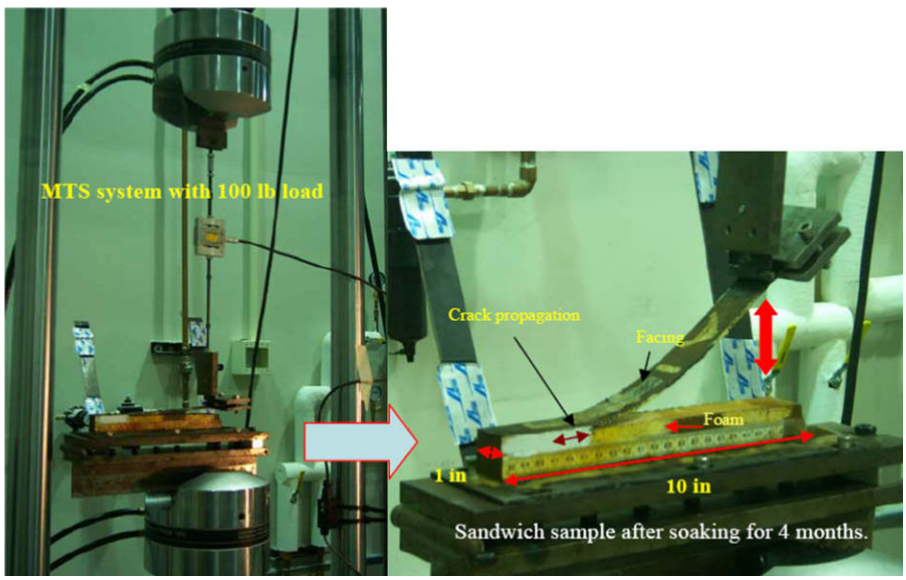

Fig. 1. Delamination testing set-up using 0.44 kN load cell, and a delaminated wet sandwich specimen.

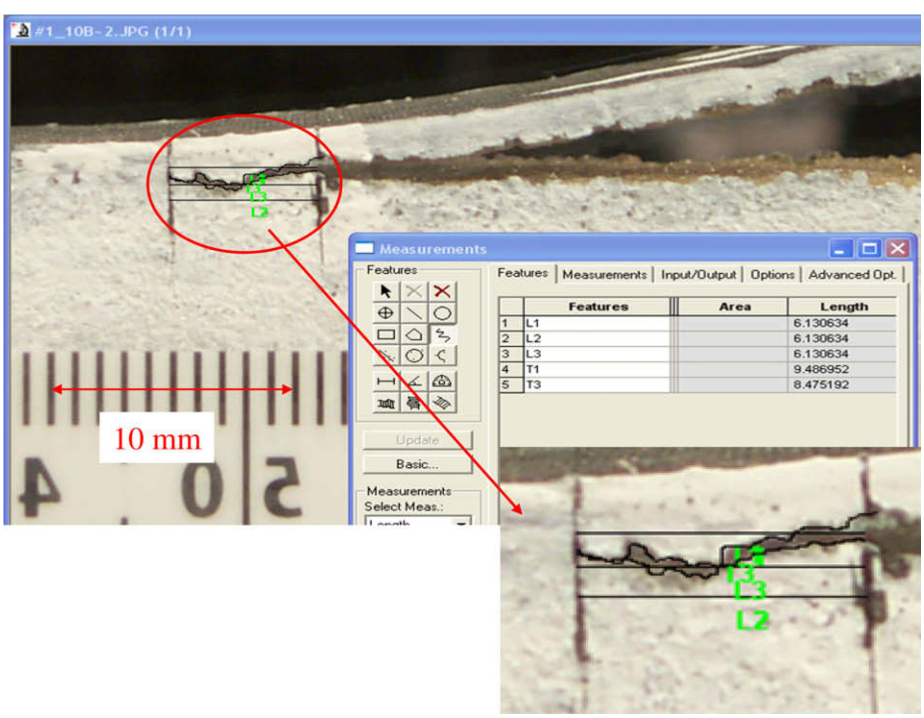

Fig. 2. Digital image analysis of a delaminated crack morphology. Dry case.