EFFECT OF SEA ENVIRONMENT ON INTERFACIAL DELAMINATION BEHAVIOR OF SANDWICH LAYUPS

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Abstract

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 samples are soaked in sea-water for target duration and are tested and fracture progression 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 found and needs to be considered for the design of ship structures.

1 Introduction

The purpose of this research is to evaluate the effects of sea water and temperature on deformation and damage of sandwich layups and on closed cell polymeric foams. The effect 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 delamination behavior of sandwich structures.

It was established in previous work [1], [2] that most of the permeated water in closed cell polymeric foams is confined in a boundary layer adjacent to the exposed surfaces and this interaction with moisture results in an expansional strain. These mechanisms enhance the growth of delaminations at the foam/carbon fiber facing interface and were estimated to reduce the stiffness and integrity of the foam material. It was also noted that a secondary mechanism of water ingress is provided by the foam's permeability. The two commonly used approaches to characterize interfacial adhesion are based on the conventional material strength and fracture mechanics based approach. Interfacial strength can be defined as the maximum stress that an interface can withstand. Expressing the strength in terms of unit stress, it could be measured by techniques such as pull test and shear test. Often used to measure adhesion, such techniques are quick and easy to perform and give values of bond strength for comparisons.

The other approach is by using interfacial fracture toughness, the amount of energy per unit area required to separate an interface that has been bonded together. This energy-based failure criterion (such as critical energy release rate or critical J-integral) is based on linear elastic fracture mechanics (LEFM). The LEFM is applicable in cases where small scale yielding (localized at the crack tip) is observed in the material components interface. In other words, the plastic zone size is limited to a small area in front of the interface crack. It is well accepted that the fracture mechanics method is a much more accurate measure of interfacial adhesion. Interfacial fracture toughness characterizes when the existing crack will advance. The crack tip deformation dissipates energy, and this is a primary contributor to interfacial fracture toughness. In this research, the potential for the carbon fiber and vinyl ester based face sheet and PVC foam core interface region to be compromised due to long term exposure to sea water was characterized. Delamination at the interface of foam core and facing can occur under three basic modes: opening or peel mode (Mode I), forward sliding shear mode (Model II), or tearing mode (Mode III), or in combination of one or more modes mentioned above [3]. In this research, tilted sandwich debond (TSD) specimen for face/core interface fracture characterization was utilized [4]. Changes in delamination fracture toughness values due to sustained sea water exposure are quantified.

2 Materials and Experimental Setup

2.1 Sandwich Panel

The composite sandwich panels of size 60 x 90 cm (2 x 3 feet) and 2.54 cm (1.0 in.) thickness were supplied to the researchers by Professor Shivakumar with North Carolina A&T University [5] and were fabricated using VARTM process. The carbon stitch bonded fabric designated by LT650-C10-R2VE was supplied by the Devold AMT AS, Sweden. This was a 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/sq.m with 315 g/sq.m of fiber in the 0° direction and 305 g/sq.m in the 90° direction. Both the directional fibers were stitched with a 14 g/sqm 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 areal density method and includes 2.2% weight of polyester stitch fiber.

2.2 Delamination Testing

Foam core/composite facing sandwich samples measuring 254 mm long, 25.4 mm wide and 29.4 mm high were cut from sandwich panels. The height dimension included the thicknesses of both faces for the sandwich panel with H100 PVC foam core (namely H100 sandwich). Pre-cracks of length 50 mm with a sharp tip were cut along the top face/core interface and the samples were loaded according to the set-up shown in Fig. 1. Loading was introduced by means of an MTS servo-hydraulic 22 kN capacity testing machine under displacement control. A very precise smaller load cell with a full scale capacity of 0.44 kN was used to perform delamination testing. The specimens were tested before (dry) and after immersion in sea-water (wet) for a target duration. The system affords most accurate observations of crack tip positions on both sides of the delaminating specimen and a near definitive determination of load levels at the onset of intermittent crack growth. To maintain a fully saturated crack tip region after each unloading, it was necessary to re-soak each "wet" specimen for at least two to three weeks prior to its subsequent loading. The digital images of the interface cracks were obtained during testing as shown in Fig. 2. Using digital image analysis software (ImagePro®), crack morphology was also determined for possible use in calculating energy release rate values.

3 Results

Typical results from an experimental data are shown in Fig. 3, where the data associated with the first two load/unload cycles are discarded in the evaluation of the critical energy release rate Gc due to the fact that these cycles started with a pre-cut crack which may not be representative of a natural crack and due to the absence of a sharp crack-tip in those cases. Typical delamination configurations are shown in Fig. 4. Note that, the delamination crack propagates close to the interface in the wet case, while it stays within the foam in the dry case. As noted, the crack path in the wet specimens tended to stay close to the face/core interface, while it tended to deviate into the interior of the foam under the dry condition, as shown in Fig. 4. This indicates a change of fracture mode mixity in the interfacial area under the wet condition. The fact that the cracks stayed along the outer edges indicates that sea-water remained confined to the outer regions of the specimens. Computational results for Gc are listed in Table 1, where values are listed for crack lengths observed on both sides of the specimens. Accordingly, exposure to sea water affects approximately a 30% reduction in Gc. Since cracks do not maintain straight fronts normal to the direction of their propagation, this may greatly affect the actual values of Gc for both dry and "wet" cases. Currently, efforts are underway to quantify the effect of actual crack morphology on the derived fracture toughness values.

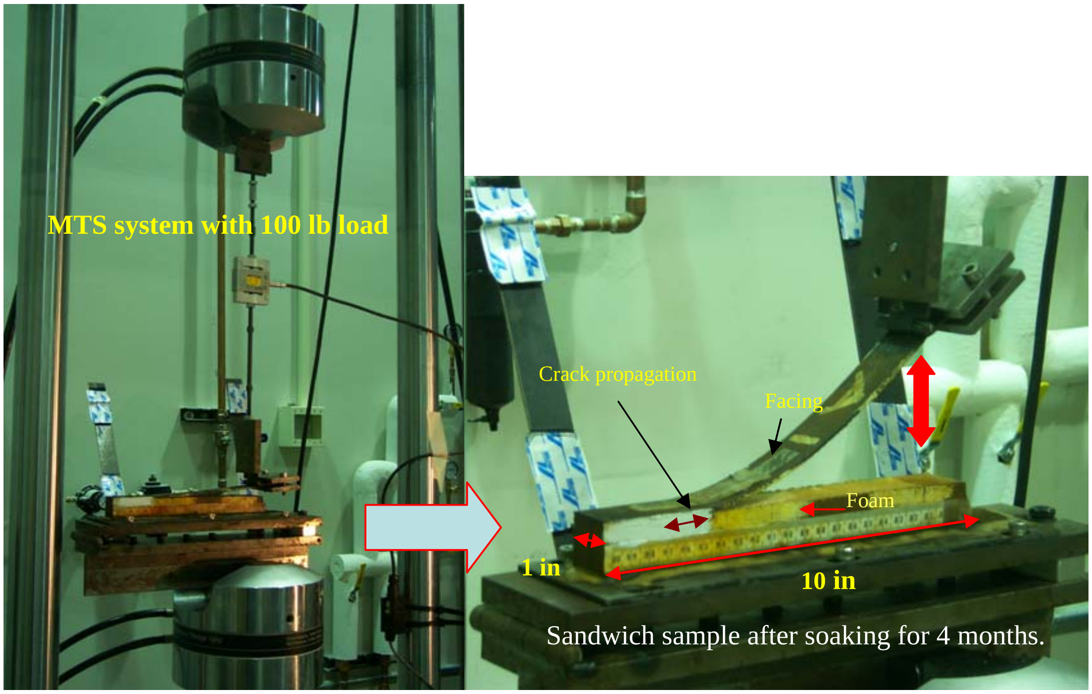

Fig. 1 Delamination Testing Setup Using 0.44 kN Load Cell

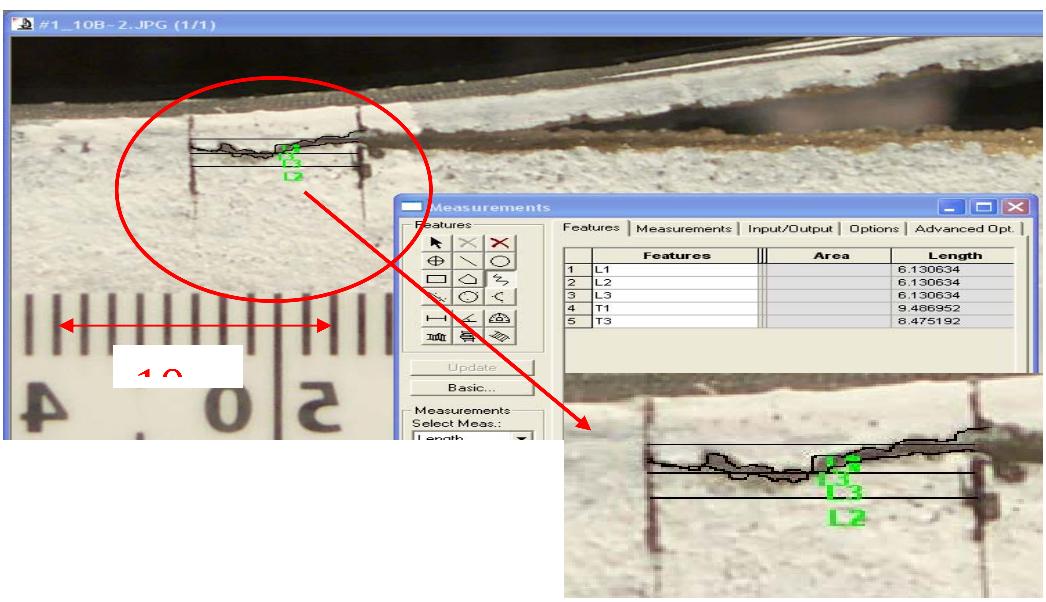

Fig. 2 Digital Image Analysis of Crack Morphology

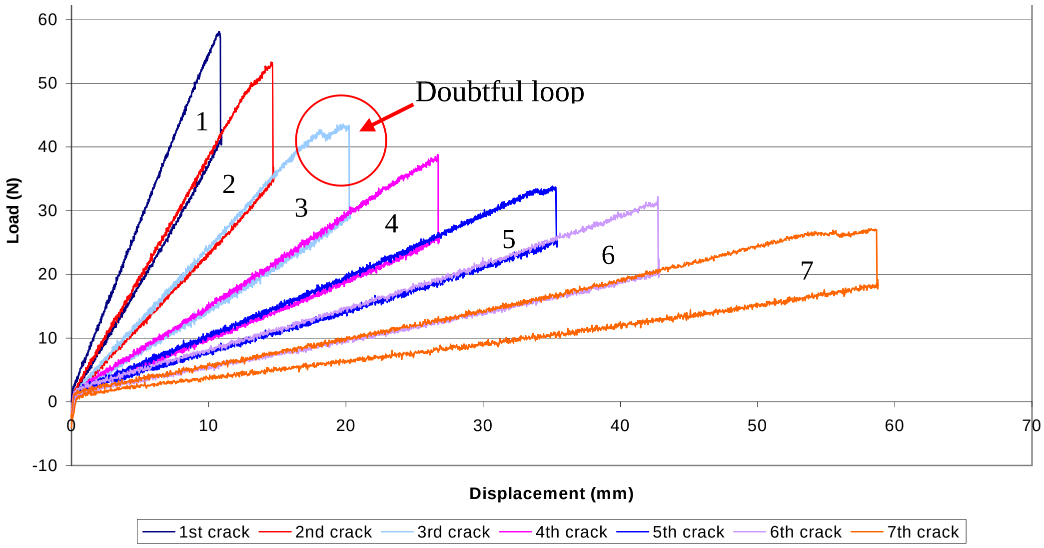

Fig.3 Interface Crack Propagation Results

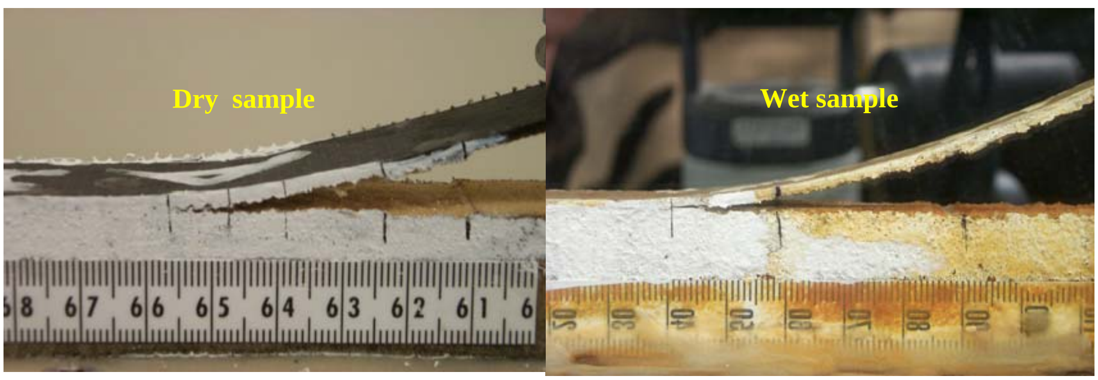

Fig.4 Typical Delamination Cracks (Dry and Wet sample)

	G_C (Front) Lower&Upper limit N/m	G_C (Back) Lower&Upper limit N/m	Representative Range (>50%) N/m
Dry	580-952	541-963	780-890
Wet	432-619	451-632	522-588
% Reduction	*25-35%*	*17%-34%*	*33-34%*

Table 1 Fracture Toughness Reduction Due to Soaking

Conclusion

Due to sustained exposure to sea-water, the delamination face/core interface fracture toughness showed a reduction of approximately 30% for carbon fiber vinyl ester based facing and PVC H100 foam sandwich. The crack path in the wet sandwich specimens stay close to the face/core interface, while it tends to deviate into the interior of the foam under the dry condition

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