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DEBOND FRACTURE CHARACTERIZATION IN SANDWICH COMPOSITES UNDER ARCTIC LOW TEMPERATURE CONDITIONS

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ABSTRACT

Mixed-mode I/II fracture characterization and measurements of low temperature fracture properties for typical naval type sandwich material configurations has been carried out using the mixed mode bending (MMB) test fixture inside a state-of-the-art climatic chamber facility. The developed test methodology is utilized to measure mixed mode fracture toughnesses as well as crack propagation speeds (da/dN) vs. cyclic energy release rate data, investigating and comparing ambient and low temperature face/core fracture behaviour at different mode-mixities in Navy type sandwich composites. Sandwich specimens were manufactured using H100 PVC foam cores and E-glass/Epoxy face sheets. All specimens were pre-cracked in order to define a sharp crack front.

1 INTRODUCTION

Sandwich structures are considered as key enablers for future and present lightweight structural applications in naval ships because of their superior stiffness/weight and strength/weight ratios compared with traditional metallic as well as monolithic structures made from composite materials.

To permit high-performance manufacture of naval vessels, it is inevitable that the structural design of the vessel will necessitate large unstiffened panels that are susceptible to large deformation under repeated cyclic loading, caused by a combination of in-service loading from a variety of sea states as well as accidental loads. Failure often occurs as a consequence of either manufacturing flaws or in-service loads experienced by the structure, such as general overload and impact events, eg. hull bottom slamming, which exacerbate the effect of the ongoing fatigue loading.

Figure 1: Royal Danish Navy patrol vessel in ice filled waters near Greenland

Naval vessels are expected to operate in a variety of climatic conditions, including arctic regions, see Figure 1. Therefore, the ability for the Navy to operate safely in arctic polar regions under the presence of ice, highlights the need for further research aimed at the influence of low temperature operational conditions on debond fracture growth in sandwich composites.

2 EXPERIMENT PROCEDURE

Sandwich composite specimens has been manufactured using Divinycell H100 cross-linked PVC foam cores bonded to quasi-isotropic face sheets made from 850 g/m2 E-glass/Epoxy non-crimp multi-axial (0/45/90/-45) Devold AMT DBLT-850. The mechanical properties of the face sheets and core have been listed in Table 1.

Properties		H100
Cell size	[mm]	0.45
Density	[kg/m^3]	100
Tensile modulus	[MPa]	130
Tensile strength	[MPa]	3.5
Compressive modulus	[MPa]	135
Compressive strength	[MPa]	2.0
Shear modulus	[MPa]	035
Shear strength	[MPa]	1.6
Shear strain	[%]	40
Fracture toughness G_c	[J/m^2]	310
Face DBLT-850 (0/45/90/-45)		
Young's modulus (E_x)	[GPa]	18.6
Poisson's ratio (v_{xy})	-	0.306
Shear modulus (G_{xy})	[GPa]	6.1

Table 1: Mechanical properties of H100 PVC foam core and fiber glass sheets [1]

Figure 1: Navy type sandwich composite MMB specimen

The MMB sandwich specimens used in this experiment have been cut out of the test panel which has been manufactured using a resin infusion process. The artificial debond starter crack has been created by placing a thin Teflon film insert at the upper face/core interface before resin injection. However, it has been observed for sandwich composite specimens with H100 core that a crack can propagate either in the core, in the face sheet or in between the face and core depending on the mode-mixity at the crack tip and the fracture toughnesses of three crack positions respectively [1]. The specimens have been cut in a rectangular shape with

35 mm width and 215 mm length, span length of 160 mm (2L), core thicknesses of 10 and 20 mm, and face sheet thickness of 2 mm.

In the resin infusion process, the face sheets have been impregnated with resin and the foam cells on the top and bottom surface of the foam core at face/core interface, which were partially open due to the foam core cutting, have been filled by resin forming a resin-rich interface layer with approximately thickness of a single foam cell (i.e. 0.45 mm). The resin-rich layer often proves to be tougher than the core, and fracture may occur in the core, just underneath the resin-rich layer, depending on the mode-mixity at the crack tip and toughness of the interface [2]. Also a pre-cracking technique has been used to ensure a realistic and sharp crack tip.

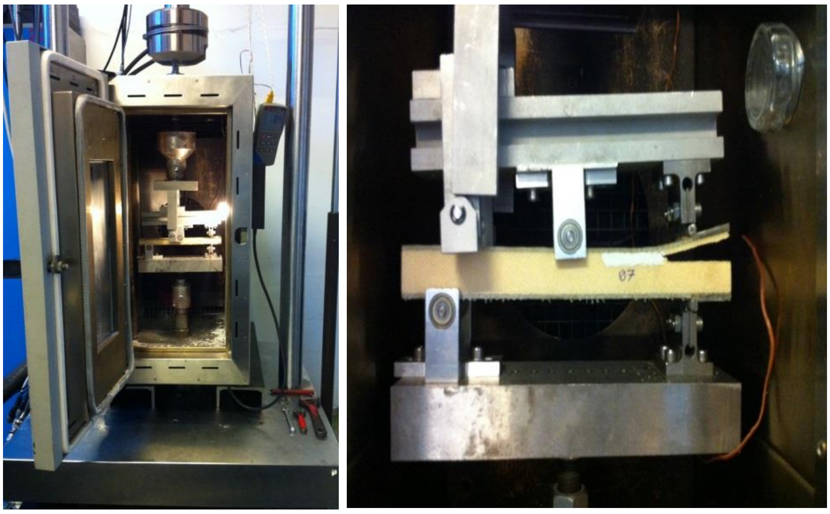

Figure 2: MMB test fixture and the climatic chamber

The climatic chamber and the MMB test fixture are shown in Fig. 2. It has been proved that the MMB test can be considered a superposition of the mode II CSB (Cracked Sandwich Beam) and mode I DCB (Double Cantilever Beam) and the load P, can be partitioned into CSB and DCB using a load partitioning parameter α [3]. The MMB compliance and energy release rate depend on the crack length, a, face and core thicknesses, mechanical properties of the sandwich constituents, geometry of the specimen and loading conditions controlled by the lever arm distance, c. Analytical expressions for the MMB compliance, C, and energy release rate, G, have been derived previously [3]:

$$C = [\frac{c}{L} C_{DCB\_upper} + \frac{c-L}{2L} C_{DCB\_lower}](\frac{c}{L} - \alpha \frac{c+L}{2L}) + (\frac{c+L}{L})^2 C_{CSB} \tag{1}$$

$$G = \frac{P^2}{2b^2} \left(\begin{array}{l} \frac{c}{L}(\frac{c}{L} - \alpha \frac{c+L}{2L}) \frac{12}{E_f h_f^3} [a^2 + 2a\eta^{1/4} + \eta^{1/2}] + \\ \frac{c-L}{2L}(\frac{c}{L} - \alpha \frac{c+L}{2L})[\frac{1}{h_c G_{xz}} + \frac{a^2}{(D - \frac{B^2}{A})}] + (\frac{c+L}{L})^2 (\frac{a^2}{8}[\frac{1}{D_{debonded}} - \frac{1}{D_{\mathrm{int}\,act}}]) \end{array} \right) \tag{2}$$

Where decomposed compliance components are:

$$C_{DCB\_lower} = \frac{a}{b}[\frac{1}{h_c G_{xz}} + \frac{a^2}{3(D - \frac{B^2}{A})}] \tag{3}$$

$$C_{DCB\_upper} = \frac{4}{E_f h_f^3 b}[a^3 + 3a^2\eta^{1/4} + 3a\eta^{1/2} + \frac{3}{2}\eta^{3/4}] \tag{4}$$

$$C_{CSB} = \frac{L^3}{6bD_{\mathrm{int}\,act}} + \frac{L}{2h_c bG_{xz}} + \frac{a^3}{12b}[\frac{1}{D_{debonded}} - \frac{1}{D_{\mathrm{int}\,act}}] \quad (5)$$

The load partitioning factor and elastic foundation modulus parameter can be expressed as:

$$\alpha = [\frac{\frac{a^3}{3}\frac{1}{D-\frac{B^2}{A}} + \frac{a}{k}\frac{1}{G_f h_f + G_{xz}h_c}}{\frac{a^3}{3}\frac{1}{D-\frac{B^2}{A}} + \frac{a}{k}\frac{1}{G_f h_f + G_{xz}h_c} + \frac{a^3}{3}\frac{1}{\frac{E_f h_f^3}{12}} + \frac{a}{k}\frac{1}{G_f h_f}}] \quad (6)$$

$$\eta = \frac{h_f^4 bE_f}{6bE_c} \quad (7)$$

Where k is the shear correction factor (k=1.2) and also A, B and D are the extensional, coupling and bending stifnesses and $D_{debonded}$ and D_{intact} are the flexural stiffnesses of the debonded region and intact region of the cracked beam respectively. Further details are provided in [3].

Quasi-static tests at -20C with different mode-mixities have been carried out in order to characterize the debond fracture of foam core sandwich composite at typical arctic conditions. To this end, several specimens have been loaded in displacement control mode inside a climatic chamber to achieve the critical load, P_c, in accordance with the MMB standard (i.e. ASTM D6671) where it has been defined as the load at which the compliance has increased by 5%, or the maximum load, depending on which occurs first along the load–displacement curve [4]. Substituting the measured P_c in Eq. (2) leads to the critical energy release rate (i.e. fracture toughness). The mode-mixity at the crack tip has been controlled by lever arm position, c, and tests have been done at several c values in order to evaluate the effect of temperature on fracture toughness, G_c, at different mode-mixities.

9 CONCLUSIONS

Mixed-mode I/II fracture characterization of low temperature fracture properties for typical naval type sandwich material configurations has been carried out using the mixed mode bending (MMB) test fixture inside a state-of-the-art climatic chamber facility. It has been observed that the measured fracture toughnesses for different mode mixities decrease at -20C compared to similar measurements at ambient temperatures.

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