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FRACTURE MECHANICS METHODS FOR ASSESSMENT OF DAMAGE TOLERANCE OF DEBONDED/DISBONDED SANDWICH STRUCTURES

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In the last 40 years sandwich composites have seen a growing popularity in a wide spectrum of different industries. Areas of application have first of all been aircraft and spacecraft, but with a decreasing fiber material price of the most commonly used fiber types, composite materials have eventually been applied on a larger scale in ships, cars, trains, wind turbine blades, off-shore installations, etc. Common to most of these weight critical applications is the need for reducing the weight of the structure to increase the strength-to-weight and stiffness-to-weight ratios and thus obtain better performance and/or an increased loading capacity. With regard to these strength- and stiffness-to-weight ratios, composites and especially sandwich composites possess a superior performance. Other advantageous properties are thermal and acoustic insulation, fatigue, corrosion and easy manufacturing of aero- and hydro-dynamically superior shapes.

One of the key aspects in a design, which does not only apply to composite weight-critical structures but in general, is to be able to take advantage of the construction materials and utilize them to their limits. This, in turn, leads to requirements for theoretical tools for accurate prediction of the loads, the structural response as well consequences of damages in the structure. However, with the increasing ability to optimize the structures to the performance limit of the construction materials and with the willingness to do so in practice, the reserve margin for structural degradation and damage tolerance becomes significantly smaller. In Fig. 1 the reliability index, Y, versus the ageing of the structure is shown for a typical structural lifetime of a structure optimized to the material performance limit. For this particular example it may be observed that the reliability index is reduced as the ageing of the structure increases. However, the structural integrity is regained because of repair every time the reliability index reaches the accepted minimum value.

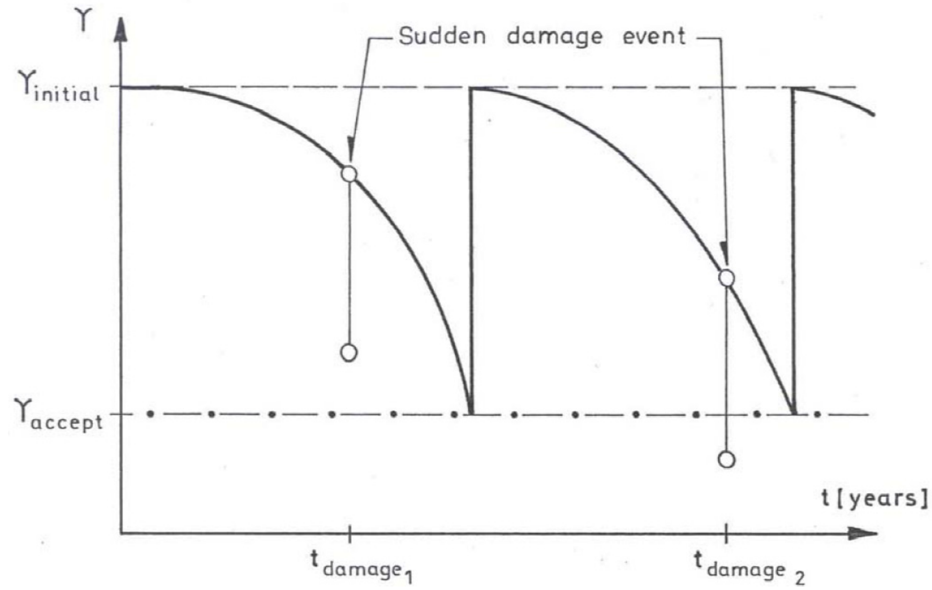

Fig. 1: The structural reliability index versus the ageing of the structure. Additionally, the effect of a sudden damage event is indicated.

In Fig. 1 the effect of the same sudden damage to the structure is indicated for two different times during the structural lifetime. The damage to the structure means that the structural integrity is suddenly reduced and the reliability index is therefore dropping. As indicated in Fig. 1, the damage is seen to be non-critical to the first damage case but critical to the second damage case, as the reliability instantly drops below the accepted value. The example emphasizes the importance of being able to evaluate the criticality of a given damage in connection with the redundancy of the structure. Furthermore, it is evident that in order to achieve highly optimized structures, which are able to operate in a stochastic loading environment, damage tolerance evaluation is needed. Furthermore, the damage tolerance approach does not only apply to the design and optimization of composite structures, but is also highly relevant to composite structures already in service and exposed to minor or major damages. Is a given damage critical for the structural integrity, or is the damage negligible? These questions are especially relevant for sandwich structures, which by nature are highly optimized structures with a high number of possible damage scenarios and consequent failure mechanisms.

Among the most critical damages to sandwich structures is debonding or disbonding (the choice of term depends on the industry segment) of the face and core layer (loss of connection between them), see Fig. 2. This kind of damage can be highly critical for the sandwich structure as the basic sandwich principle is compromised when the connection between the face and the core layer is lost. Over the last 30 years, investigations of this damage type have been carried out within a range of industry segments, beginning with Zenkert (1990) [1], who investigated the strength of foam core sandwich beams with various debonds and interface propagated shear cracks using the finite element method and experimental testing. A wide range of other investigations have over the years been presented in the literature aiming at different sandwich material systems within marine, wind energy, aeronautical and space applications, using both experimental and numerical tools to model debond propagation using experimental fracture mechanical characterization data from a range of different fracture characterization specimens.

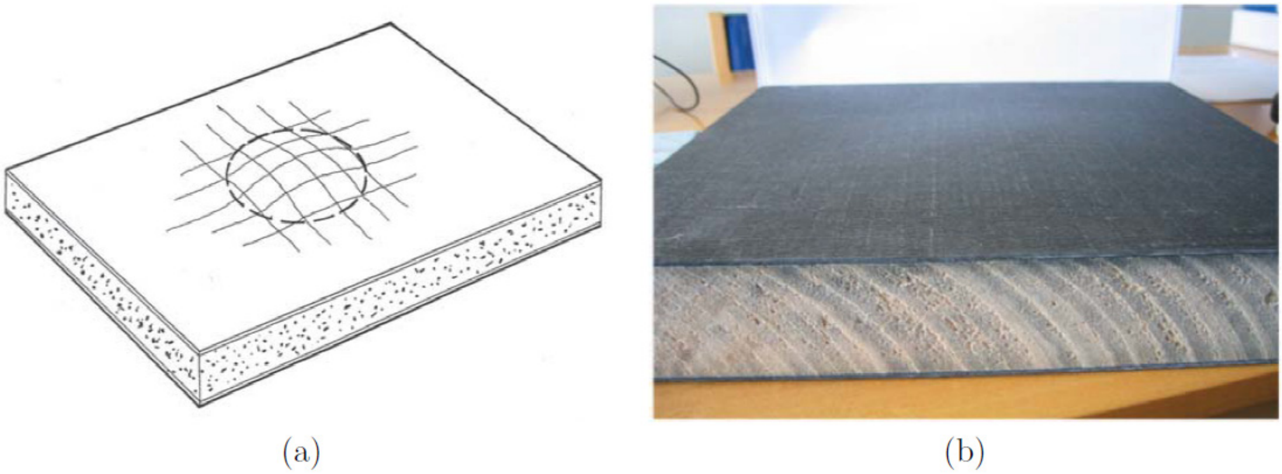

Fig. 2: Example of a debond in a CFRP/PVC foam core panel. (a) Schematic representation, (b) photo courtesy of Royal Institute of Technology, Sweden.

In addition, the underpinning generic fracture mechanics for an interface crack between two dissimilar materials has over the same time span developed from the fundamental work by Professor J. W. Hutchinson and Professor Z. Suo, who were the first to establish a firm foundation for the analytical description of the bi-material interface fracture mechanics, Hutchinson and Suo (1992) [2], Suo (1990) [3] and Suo and Hutchinson (1990) [4]. Their work have the recent years been expanded by a number of authors to address sandwich specimens with a full set of external loading configurations, opening the door for possible standardization of fracture characterization specimens and methods for sandwich composites.

The current plenary talk will include a review and overview of the work performed in the field of damage tolerance of debonded sandwich structures focusing on the development of fracture mechanics based analysis and test methods for the assessment of residual strength and life-time of typical sandwich structures. Analysis and test methods both on the coupon, component and structural length-scale will be presented and recommendations will be given for safe engineering analysis and assessment of debond damages in a range of typical debond damage cases from the marine, wind energy and aeronautical industries, see Figs. 3-5.

Fig. 3: Debond damages as a result of slamming on the wet-deck bottom structure in a catamaran ship.

Fig. 4: Disbond damage in a wind turbine blade as a result of torsional induced panel breathing in the max-cord section.

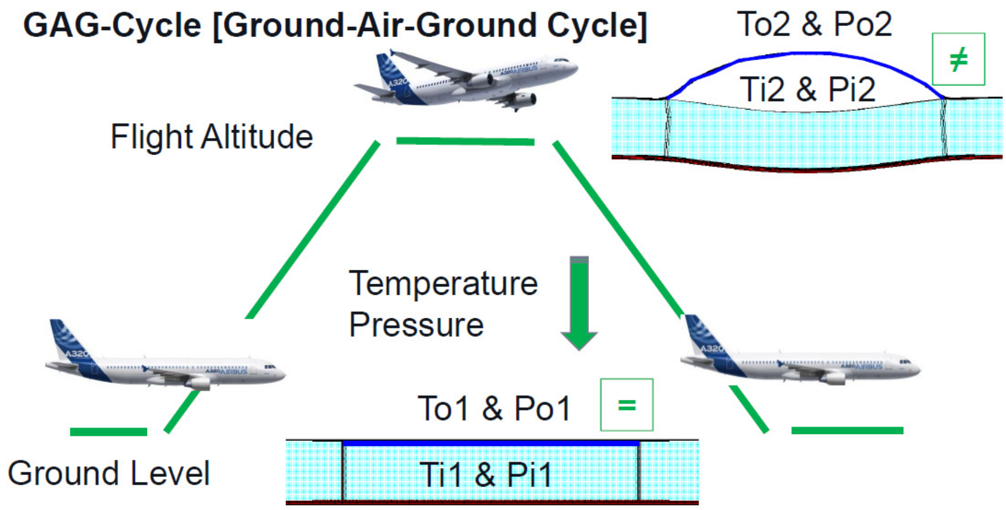

Fig. 5: Disbond damages in an aircraft honeycomb sandwich panel as a result of Ground-Air-Ground flight operational induced pressure differences. Photo courtesy of Airbus.

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