Damage tolerance analysis of bonded composite scarf joints using cohesive zone models: limitations & challenges

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Abstract

Although bonded repairs to composite aerospace structures have many advantages over mechanically fastened approach, however, their application towards primary structures has been limited. The situation is due to the lack of non-destructive techniques to assess the bond quality. For bonded repairs to be permissible for larger damage states, improvements are required in several fronts including inspection technology, validated models for fatigue and damage tolerance. While Cohesive Zone Modelling (CZM) technique has been extensively used for damage initiation and crack propagation investigation, its capabilities and limitations on damage tolerance analysis of composite scarf joints under service conditions are not thoroughly addressed in the open literature.

The performance of a scarf repair on an aircraft structure can be affected by several factors including the flaw size/location, supporting boundary conditions, scarf angle, and composite layup. As modern aerospace design requires tighter tolerances, the need for models to accurately predict progressive failure of bonded repairs becomes apparent. Therefore, this paper examines the limitations and capabilities of CZM based models to analyse damage tolerance of bonded scarf joints under operational conditions. The findings from this study enhance the current body of knowledge towards a damage tolerant approach of scarf repair design and give insight into some of the potential failure mechanisms which degrade joint's performance.

Using an extensive experimental program, the influences of joint's geometry, criticality of defect's location and size as well as the effects of boundary condition (supported & unsupported) on the failure behaviour of scarf joints under tensile loading were studied. After analysing the fracture surfaces of the failed coupons, evidence of composite failure along the adhesive-adherend interface was identified as the primary cause of ultimate failure for all cases. It was identified from experimentation that the level of composite failure along the length of the joint does vary in magnitude depending on geometry, layup and boundary condition setup. Typically, in the regions where 45° and 90° plies are present, there were greater levels of composite failure compared to areas where 0° plies exist. The reason for greater damage in the 45° and 90° ply regions is correlated to matrix dominated failure mechanisms. Having identified the failure mechanisms, an attempt was carried out to examine the capability and limitations of CZM-based numerical methodologies in capturing the composite failure along the bondline under service conditions.

The numerical approach used in this study was capable of capturing the strength of pristine joints as well as the increase in the strength predictions when a tip-flaw is relocated to a centre-

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flaw location. In addition, there was a general agreement between experimental results and numerical predictions for the 5° scarf angle and 3° soft adherend layup cases. Furthermore, the predicted strength of a pristine joint for doubler supported cases was in good agreement with the experimental results. While the strength prediction for a pristine sandwich support case is slightly over predictive, results for supported tip-flaw cases are quite conservative. Upon inspection of the sandwich supported cases, under-predictions of 42% and 44% are present for both the 20% (15 mm) and 40% (30 mm) tip-flaw cases, respectively. The reasons for these under predictions can be linked to the inability of current methodologies to capture all associated mechanisms such as plasticity.

Fig. 1 illustrates the maximum shear stress experienced through the centre of the bondline just before rapid failure in the joint. It is evident that the maximum shear stress at portions of the adhesive layer has exceeded the yield stress due to the 0° ply terminations in the pristine repair (NF) or due to the crack tip in the pre-flawed models (TF). As the scarf models were analysed assuming a linear-elastic material model, plasticisation of the adhesive layer was prevented. The large under predictions of the supported TF cases may be a consequence of neglecting the energy required to plasticise the adhesive. Therefore, adhesive non-linearity could be introduced into future modelling to further understand the damage tolerance characteristics.

Plasticity in the adhesive layer would be critical to implement into the analysis if a design methodology was to incorporate hot-wet conditions, as it is known that large inelastic characteristics exist. However, this would be difficult to achieve due to the highly non-linear nature of the failure response. Therefore, further consideration for accurate modelling implementation is required.

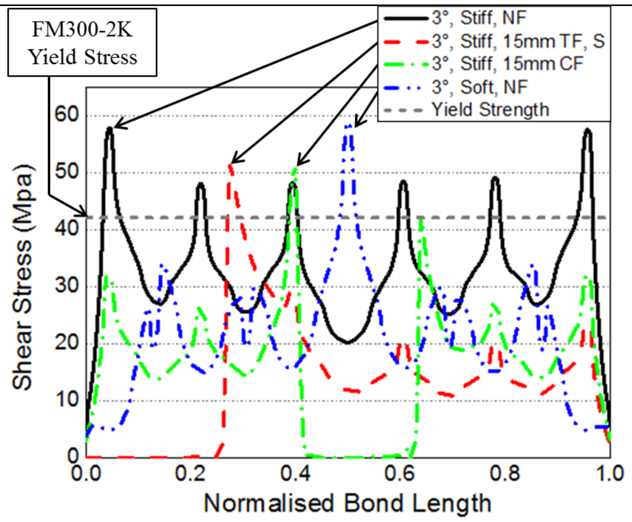

Figure 1: Shear stress distribution along the bondline for various flaw conditions immediately prior to failure of each joint

Keywords
Adhesively bonded joints; damage tolerance; finite element; scarf repair; bondline flaw