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Numerical study on the onset of initiation of debond growth in adhesively bonded composite joints

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ABSTRACT

Adhesively bonded composite joints plays, an important role in the modern composite structures assembly to realize light weight structures than the mechanical fastening. However, in the process of adhesive bonding of composite components can result in manufacturing flaws namely debonds. Debonds can change the structural response of adhesively bonded joints significantly in compressively loaded aerospace structures. In general, the prediction of the maximum load that composite structures can withstand is very crucial due to the anisotropic nature of the composite material. The presence of manufacturing defects like debonds adds further complexity to the prediction of failure mechanisms of the composite joints. The present study is focused to ascertain the effective load carrying capacity of the adhesively bonded composite joints in the presence of closed debonds. The finite element method (FEM) is used to predict the onset of initiation of debond growth in conjunction with virtual crack closure technique (VCCT). The studies are carried out for various bonded laminate configurations in the frame work of VCCT using general purpose FE code (ABAQUS). The influence of parameters such as laminate sequence, debond location, size and its shapes (square and circular) are investigated.

1. Introduction

The composite technology is widely used in aerospace applications to harness its specific characteristics. Thin walled composite panels are among the most utilized structural elements in aerospace structures. They are made of advanced composite parts/components, joined together to form the structure of the required geometry and are subjected to any combination of in-plane, out-of-plane and shear loads during its application. Adhesive joints are employed in advanced aerospace composite structure assemblies to realize light weight structures. However, composite structures are susceptible to performance reduction in the presence of defects, due to manufacturing issues or damages during service loads. Debonds occurring in the adhesively bonded composite joints due to manufacturing issues have great impact on the load carrying capability and they are a major concern in aerospace structures. Hence it necessitates the assessment of damage tolerance of bonded composite joints with inherent flaws (like debonds) in the design of modern aerospace vehicles where adhesive joints are widely used.

Early studies on composite skin-stiffener debonded configurations are reported by Wang et al. [1]. Yap et al. [2] have proposed a comprehensive finite element method to study the effect of skin-to-stiffener debonding. Pradhan et al. [3] carried out parametric studies on debonding in adhesively bonded composite joints and their results revealed that strain energy release rate is sensitive to the orientation of fibers in the composite adherends.

Studies on buckling of composite plates having debonds were reported in literature. Kim and Kwon [4] have studied the effect of open disbonds in the composite sandwich panel flange joint under compressive loading environment. They have also reported that debond growth initiation was strongly affected by adhesive fracture toughness and flange stiffness. Debond length and flange width strongly affect buckling but were found to mildly influence debond growth initiation. The significance of adhesive thickness and curing conditions on the critical energy release rate also envisaged. Mikulik et al. [5] employed fracture mechanics based crack tip element methodology to predict the skin-to-stiffener separation. da Silva et al. [6,7] presented an extensive survey on the analytical models for adhesively bonded joints both single and double lap joints and their review reveals that almost all models for lap joints are two dimensional and linear elastic for both adherends and adhesive.

Damage tolerant design is very challenging and requires expertise in damage mechanics, fracture mechanics, structural mechanics, material science, and physics to guide the experimental and analytical work. To

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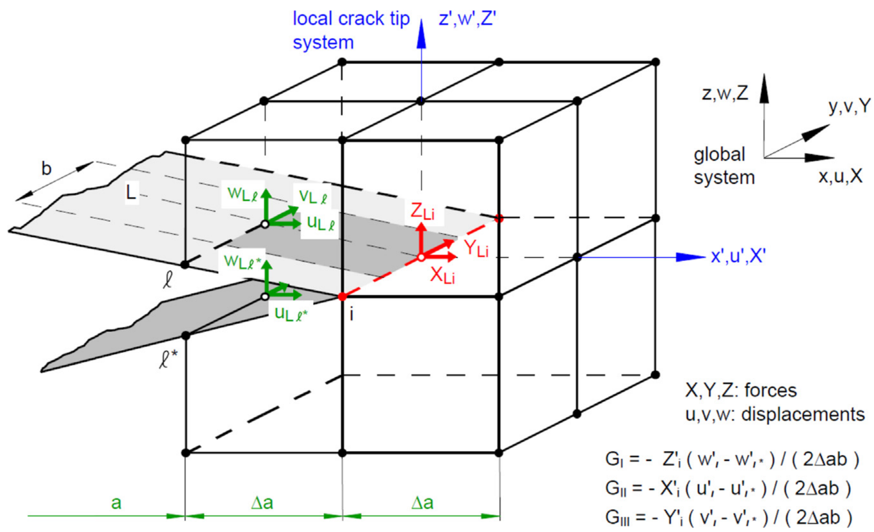

Fig. 1. Virtual Crack Closure Technique (VCCT) [20].

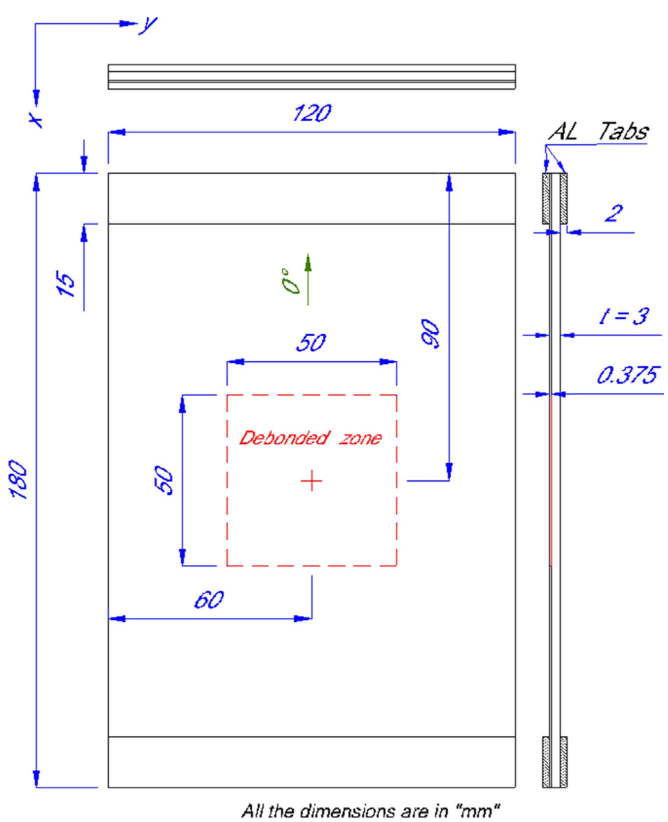

Fig. 2. Geometrical descriptions of specimen configuration for the prediction of onset of debond propagation.

acquire the knowledge on damage tolerant design, it is essential to know the effect of active debonds on the bonded joints during loading. Though the studies on the adhesively bonded joints with debonds are reported in literature, it is evident that literature on onset of growth of closed debonds on the adhesively bonded joints are limited. This motivated the study on the structural response of adhesively bonded composite joints containing closed (embedded) active debonds. The finite element (FE) tool has been proved useful in predicting the behavior of composite structures in the presence of active defects. One of the most popular methods implemented in FE tool to analyze debond/crack propagation is Virtual Crack Closure Technique (VCCT), based on fracture mechanics concepts, which is detailed by Krueger [8]. The method allows obtaining the strain energy release rates and is based on the assumption that, when a crack grows the energy released in this process is equal to the work necessary to close the crack to its initial length before propagation.

The novelty of the VCCT method is more suitable approach to study the pre-existing flaw [9] like debond in the adhesively bonded joints, which is widely used in literature. Especially the VCCT method clearly indicates the contributions of the three fracture modes (opening, sliding and tearing modes) by means of computed fracture energy based on the nodal displacements in the respective directions [10].

The present work is attempted with the numerical studies on the initiation of onset of debond growth using VCCT method based on the confidence gained from literature [11,12], where in VCCT approach is validated with experimental results for the various cases of delamination / debond growth studies. The alternate method to analyze delamination / debond growth studies are cohesive zone modeling. The cohesive zone model (CZM) is based on damage mechanics [9,13] using strength properties to predict the initiation of occurrence of failure i.e., delamination / debond in composites. The strength properties are characterized by a traction–separation law based on almost arbitrary and empirical parameters. The selection of several material parameters for CZM based elements is not easily obtainable from standard experimental tests [14,15]. The VCCT model, instead, uses only toughness properties (G_C) as material parameters which are usually available from a standard experimental characterization campaign on a material system, more over it is useful to identify the contribution of each mode of fracture / which mode dominates in the growth of debond [10]. The VCCT approach is advantageous because only a single FE solution step is used for the derivation of the energy release rate (Gi) components [12,16].

The novelty of the present work is to simulate the onset of debond growth with simple computational model using finite element method in conjunction with virtual crack closure technique to understand the structural behavior of debonded structure subjected to axial compression. The objective of the present work is to perform a comprehensive numerical study on the onset of initiation of debond growth in adhesively bonded composite joints under compressive load. The influence of parameters such as laminate sequence, debond location, size and its shapes (square and circular) are investigated using VCCT with mixed-mode failure criteria.

2. Methodology

A zone of debond can be treated as crack, so the fracture mechanics