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Stress analysis of composite adhesive bonded joints under incipient failure conditions

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Abstract

Composite structures with their remarkable properties often require assembling different components and repairing the damaged regions by employing mechanical or adhesive bonding joints. Among the bonding techniques, adhesive bonding is considered the most diffused and efficient method.

Analysis of stress distribution that develops in the joint is a crucial field of research to put effort with the aim to develop engineering strength criteria. Once an adhesive bonded joint is subjected to the axial tensile load, shear and peel stress intensification takes place at the ends of the overlap. With regard to the literature, it can be concluded that there are few reliable predicting tools for brittle adhesives, for which failure usually initiates at the edge of the bonding area and propagates through the interface region. The aim of this paper is an investigation on stress field in single-lap joint (SLJ) and scarf-lap joint (ScJ) under the tensile loading. A two-dimensional numerical analysis by employing Finite Element Method (FEM) and a developed analytical solution were implemented to realize the correlation of the results. Furthermore, a comparison between possible failure criteria was performed by using FE results. Adherend thickness, overlap length, and scarf angle were considered as the joint geometry parameters. Effects of these parameters on the fracture behaviour of bonded joints were evaluated.

Keywords: Bonded joint, Brittle adhesive, Finite element method, Composite structure;

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1. Introduction

Composite structures with their notable features and widespread of applications are considered as an important subject to put the effort in study and research. Distinguished industry sectors from the traditional to the high technology required industry such as automotive, aerospace and sports equipment use composite structures.

In some structures due to complex shape or difficulty in assembling, bonded joints are needed. Damaged components are required to be repaired as well through this technique also. Adhesive bonding is an effective and diffused methodology which offers simple and light assembling and provides more uniform stress distribution in comparison with other types of joining. Increased willing to implement mentioned technique, push researchers to study on constraints of limitations to solve and optimize them.

There are many configurations of joint design. Single-lap joint (SLJ), double-lap joint (DLJ), scarf-lap joint (ScJ), juggle-lap joint (JLJ) are some of the standard types that each has appointed features coming with the design to match with the loading conditions. The strength of the bonded joints is affected by several parameters that can be categorized into; local geometry (adherend thickness and width, adhesive thickness, overlap length and overlap end geometry), material properties and environmental conditions. Several studies have been carried out to define the optimal thicknesses of the adhesive and adherend (Taib et al. (2006), Ji and Li (2013) and Castagnetti et al. (2011)). Although any universal relation has not been found between strength and adhesive, however, experimental studies recommend a thickness of 0.1-0.2 mm for adhesive to achieve the maximum strength (Gleich et al. (2011)).

Overlap length as an efficient parameter has been considered to be investigated in the literature as well (Li et al. (2015), Reis et al. (2005), Neto et al. (2012) and Campilho et al. (2013)). With respect to the reports, joint strength increases by the overlap length increases. Throughout the study on overlap length, mechanical properties of the components should also be kept in mind. For instance, Neto et al. (2012) illustrates that in the case of ductile adhesive, the failure load increases proportionally with the overlap length, while for the brittle adhesive the failure load increase up to a certain length and then remained constant.

With respect to the applied load, joint geometry, and component properties, adhesive bonded joints usually experience three distinct failure types: adherend failure, adhesive failure (failure at the interface) and cohesive failure (ASTM D5573) (Fig. 1.). Adhesive and cohesive failures can be classified together as the bondline failure. Predicting of the accurate stress and strain fields and applying a reliable failure criterion are the significant difficulties in the design of adhesive composite bonded joints.

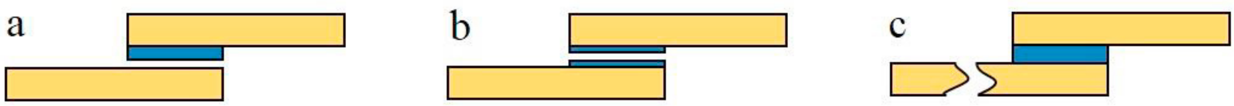

Fig. 1. (a) Adhesive Failure: Failure of the joint at the adhesive/adherend interface; (b) Cohesive Failure: Failure of the adhesive layer; (c) Adherend Failure: The adherend fails and not the adhesive

In accordance with the literature, there is no a universal failure criterion to implement in satisfactory design. Therefore, several researchers studied analytical and numerical methods to develop and improve the predicting tools for the joint strength.

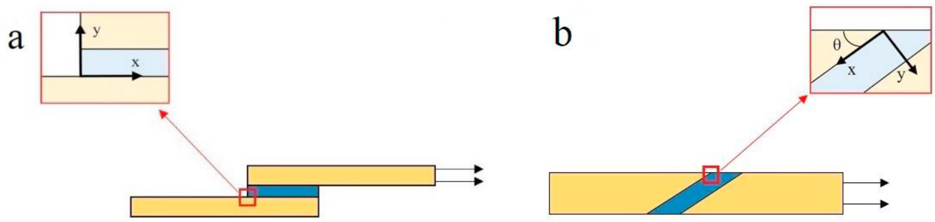

Fig. 2. Joint configuration and local geometry at the singular zone (a) Single-lap joint; (b) Scarf-lap joint