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Numerical FEM Evaluation for the Structural Behaviour of a Hybrid (bonded/bolted) Single-lap Composite Joint

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Abstract

The structural behaviour of a single-lap hybrid (bonded/bolted) composite joint subjected to a tensile external load was evaluated by means of the Finite Element Method (FEM). In particular, the distribution of stresses acting in its adhesive layer was compared with that relative to the case of a simply adhesive bonded joint. Furthermore, the load transferred by the bolt was determined at different characteristics of the adhesive and of the applied external tensile load, corresponding to both single and double bolt configuration. The obtained values were in turn compared with experimental data found in literature, so validating the produced numerical simulations.

Keywords: hybrid joint; composites; FEM; ANSYS®; adhesive; bonded; bolted; HI-LOK™; Drucker-Prager yield criterion

1. Introduction

In many industrial sectors, particularly aerospace, develop and use of composite materials is very relevant. These materials allow the production of goods relatively complex and of big dimensions, the use of joints results to be always necessary for creating complex structures. Traditionally joints between composite materials were made by a mechanical fastening, however this technique shows various disadvantages such as high stress concentrations at the

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hole, also due to a localised load transfer, which reduces considerably the fatigue and fracture strength of the joint. For this reason, the adhesive bonding technique is preferred in the joining of composite material parts. By this technique the load can be transferred in a continuous manner allowing a better stress distribution. Furthermore, the absence of holes in such joining of composites avoids the deterioration of mechanical characteristics and structural integrity due to fibres cut.

In many cases adhesive bonded joints are reinforced through the use of rivets. Traditionally the combination of mechanical fastening and adhesive bonding was considered useless in order to structural performance. However, the evaluations here made are aimed to the study of high performance aerospace joints, characterized by high modulus epoxy resin adhesives. In this case the adhesive layer transfers most of the load, without having appreciable benefits in the performance adding bolts. In fact, only by using a low modulus adhesive a better load distribution between bolt and adhesive was obtained, giving to the joint a greater strength, stiffness and fatigue life. Moreover, the use of the bolt allowed to avoid premature joint fractures due to defects inside the adhesive and allowed the alignment of the structures to be joined during the adhesive cure cycles (Kelly (2006)).

In the present work numerical analyses by Finite Element Method (FEM), for the evaluation of the structural performance of a single-lap hybrid joint subjected to an external tensile load were made. In particular, by means of the software ANSYS®, the stress distribution acting on the adhesive was determined and compared with that relative to a simply adhesive bonded joint. Moreover, the load transferred by the bolt was estimated for varying adhesive characteristics and applied load, with one or two bolts. These results were then compared to the experimental ones for the validation of the numerical simulation.

Kelly (2005) analysed the load distribution in hybrid composite single-lap joints through 3D FEM including the effects of bolt-hole contact and non-linear material behaviour. By means of a parametric study, he investigated the effect of joint design parameters on the load transferred by the bolt. Moreover, a joint was experimentally equipped with an instrumented bolt, used to measure the load transfer in the joint. Measured bolt load values were compared to predictions from FEM and results showed good agreement. Kelly (2006) continued the previous work focusing on strength and fatigue life of hybrid (bonded/bolted) joints with CFRP (Carbon Fiber Reinforced Polymers) adherends. He determined experimentally the effect of adhesive material properties and laminate stacking sequence on joint's structural behaviour and failure modes. Hybrid joints with lower modulus adhesives showed greater strength, stiffness and fatigue life in comparison to simply adhesive bonded joints. Hybrid joints with high modulus adhesives showed no significant improvement in strength although increased fatigue life was observed due to the presence of the bolt. Ireman (1998) made a 3D FEM analysis of bolted composite joints to determine non-uniform stress distributions through the thickness of composite laminates in the vicinity of a bolt hole. Experimental elongations, strains, and bolt load on test specimens were measured to validate the numerical model and a number of parameters such as laminate layup and thickness, bolt diameter and type, clamping force and lateral support was varied, each analysed by using a 3D FEM. Generally, comparison between computed and experimental results showed good agreement. Barut and Madenci (2009) developed a semi-analytical solution method for stress analysis of single-lap hybrid (bolted/bonded) joints of composite laminates under in-plane and lateral loading. The laminate and bolt displacements were based on the Mindlin and Timoshenko beam theories, respectively. Adhesive displacement field was expressed in function of those of laminates by using the shear-lag model. Governing equilibrium equations were based on the virtual work principle. The capability of the approach was validated by demonstration problems, including the analysis of bolted and bonded joints and hybrid joints with and without considering a dis-bond between adhesive and laminates. Paroissien et al. (2007) presented two 1D elastic analytical models for the determination of the load transfer in a hybrid (bolted/bonded) single-lap joint. The first one developed the integration of the local equilibrium equations with an elastic-plastic approach. The second one used the FEM, introducing a new element called "bonded-bar". The two approaches allowed to analyse the load transfer and to evaluate the influence of different geometric and mechanical parameters. Hart-Smith (1985) considered the combination of adhesive bonding and mechanical fastening for fibrous composite structures. Analyses of undamaged structures showed that, because the adhesive bond load path is so much stiffer than the load path through bolts or rivets, the combination was not stronger than a well-designed bonded joint alone. However, the combination of bonding and bolting seemed to be useful for repair and prevent damage from spreading of plates. Studies involved large stepped-lap composite to metal joints. Imanaka et al. (1995) investigated the strength characteristics of adhesive/rivet combined lap joints. They made fatigue tests on rivet, adhesive and adhesive/rivet combined joints with different lap widths, adhesive and rivet