Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 167 (2016) 168 – 175

Procedia Engineering

www.elsevier.com/locate/procedia

Comitato Organizzatore del Convegno Internazionale DRaF 2016, c/o Dipartimento di Ing. Chimica, dei Materiali e della Prod.ne Ind.le

Numerical Investigation of the Failure Phenomena in Adhesively Bonded Joints by Means of a Multi-Linear Equivalent Plastic Stress/Strain Approach

A. Riccio[a,*], R. Ricchiuto[a], F. Di Caprio[b], A. Sellitto[a], A. Raimondo[a], F. Scaramuzzino[a]

[a]*Department of Industrial and Informatics Engineering, Second University of Naples, via Roma 29, 81031 Aversa (CE), Italy*
[b]*Airframe Design and Dynamic Lab., Italian Aerospace Research Centre (CIRA), via Maiorise snc, 81043 Capua (CE), Italy*

Abstract

In this work, a multi-linear material model for elastic-plastic response of ductile adhesives is proposed. Indeed, the proposed formulation allows to evaluate equivalent stress and strains to be used as material model input in FE commercial codes instead of the classical true stress and true strains. The presented model, which is capable to simulate the plasticity related phenomena and the failure event, has been implemented in the FEM code ABAQUS and used to numerically simulate the mechanical behaviour of adhesively bonded joints in traction. Several joints configurations have been considered with ductile, fragile and mix adhesives' behaviour to test the effectiveness and the range of applicability of the proposed model. Encouraging comparisons with literature experimental data demonstrates the added value of the suggested material model in predicting the failure of adhesively bonded joints.

Peer-review under responsibility of the Organizing Committee of DRaF2016

Keywords: Bonded joints; Ductile adhesives; Multi-linear material model; Composite repair; Finite element model

1. Introduction

Composite materials are widely used in commercial and military aerospace applications because of their high specific elastic modulus and strength. Fast growth in employment of composite structures has consequently led to deep interest in composite repair technologies [1]. Design of composite joints reveals itself to be as a very important

* Corresponding author. Tel.: +39 081 5010 407; fax: +39 081 5010 204.
*E-mail address:*aniello.riccio@unina2.it

Peer-review under responsibility of the Organizing Committee of DRaF2016
doi:10.1016/j.proeng.2016.11.684

task for the structural efficiency of repaired composite structures. Usually, the joining methods for composite structures are classified into two main categories, i.e. mechanical and adhesive. Generally, mechanical bolted joints involve weight increase, stress concentration around the drilled holes and variations in the structure shape and thickness. On the other hand, bonded joints does not hardly affect the stress distribution and the load distribution; however, they may be sensitive to surface treatments and environmental conditions, such as temperature and humidity [2-3]. The benefits of adhesively repaired composite structures, makes their use spreading as much as the need of a continuous improvement of design techniques. To this end, the Finite Elements Method proves to be a valuable and effective tool. It gives the possibility to evaluate the stress distribution in the adhesive layer with good accuracy [4-9] providing the chance to minimize stress and strain peaks in order to guarantee adequate joint performances in terms of strength and reliability [10-12]. The real difficulty within the FE modelling is the definition of a valid material model capable of simulating the adhesive mechanical behaviour. The adhesives may present a non-negligible degree of ductility resulting in more or less extended non-linear response before failure onset and propagation. While a number of works analyse the elastic-plastic phase of the joints to compute the stress distribution within the bonded area [13-19], others have focused their efforts into defining the joints' strength mostly making use of the Cohesive Zone Model [20-22]. However, it looks useful to take simultaneously into account non-linear response, failure initiation and damage growth in order to have a comprehensive outlook of the phenomenon.

The aim of this work is the formulation of an effective method to simulate the elastic-plastic and failure behaviour of adhesives. The implemented model proposes the computation of equivalent stresses and strains as input to the FE code material model rather than the usual true stresses and true strains. The methodology, meant to be applied to bonded joints such as single laps and scarfs undergoing mainly shear stress, has been tested thanks to comparisons with the experimental data provided in [23] for adhesives holding different degrees of ductility (frail, extensive plasticity and mid-plasticity). Thanks to a parametric study, performed by means of the Finite Element code ABAQUS, the influence of several numerical model aspects has been assessed.

In Section 2 the formulation of the developed method is introduced. In section 3, a simple shear case is analysed in order to validate the model together with a comparison with alternative input data. Finally, with the purpose to assess the effectiveness of the proposed method, section 4 presents a numerical-experimental correlation activity performed on a series of single lap joint tests by adopting different numerical approaches.

2. A Multi-linear Input Curve Approach: Theoretical Background And FEM Implementation

In order to model the plastic behaviour of a material, ABAQUS requires, as an input, the uniaxial true stress and the equivalent plastic strain data without the chance to input, at the same time, the tensile and shear plastic stress-strain curves. In literature, it is possible to find a variety of approaches, adopting as input data Shear True Stress vs. Plastic Strain, Tensile True Stress vs. Plastic Strain or curves specifically calculated for the investigation of specific phenomena. However, the most of these alternative methods was found not able to represent the category of phenomena investigated in this work.

Among the studied literature approaches, Ban et al. [24] propose the calculation of a multi-linear curve to use as input to the numerical model to predict the failure load of single lap joints. In [24] the need to use the shear stress-strain curve of the adhesive is pointed out because the adhesive joints mainly undergo shear stress. The multi-linear curve is calculated by means of the Von Mises criterion as:

$$\begin{aligned} \sigma_y &= \sqrt{3}\tau_y \\ \varepsilon_y &= \frac{\sqrt{3}\tau_y}{2G(1+\nu)} \end{aligned} \qquad (1)$$

where σ_y is the tensile yielding stress, τ_y is the shear yielding stress, ε_y is the tensile yielding strain, ν is the Poisson's ratio and G the shear modulus. The obtained curve is similar to the tensile stress-strain curve of the adhesive, but its ultimate strain is larger than that of the tensile curve.