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Simulation of self-piercing rivetting processes in fibre reinforced polymers: material modelling and parameter identification

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Abstract

This paper addresses the numerical simulation of self-piercing rivetting processes to join fibre reinforced polymers and sheet metals. Special emphasis is placed on the modelling of the deformation and failure behaviour of the composite material. Different from the simulation of rivetting processes in metals, which requires the modelling of large plastic deformations, the mechanical response of composites is typically governed by intra- and interlaminar damage phenomena. Depending on the polymeric matrix, viscoelastic effects can interfere particularly with the long-term behaviour of the joint. We propose a systematic approach to the modelling of composite laminates, discuss limitations of the used model, and present details of parameter identification.

Homogenisation techniques are applied to predict the mechanical behaviour of the composite in terms of effective anisotropic elastic and viscoelastic material properties. In combination with a continuum damage approach this model represents the deformation and failure behaviour of individual laminae. Cohesive zone elements enable the modelling of delamination processes. The parameters of the latter models are identified from experiments. The defined material model for the composite is eventually utilised in the simulation of an exemplary self-piercing rivetting process.

Keywords: Self-piercing rivetting, Fibre-reinforced composites, Damage, Homogenisation, Cohesive Zone

1. Introduction

In the light of an increasing ecological awareness, the consistent lightweight design has become a major focal point of research and development especially in the automotive, railway and aircraft industries. Hybrid designs that combine different materials, e.g. metals and fibre reinforced polymers (FRP), are considered a promising approach to cost-effective lightweight components. While these multi-material designs provide considerable synergy effects by merging advantageous properties of various materials, joining technologies are essential for the practical application of hybrid materials and structures.

Self-Piercing Rivetting (SPR) has been demonstrated to be a fast and robust technique to join dissimilar sheet metals, see for instance the review of He et al. (2008). In contrast to bolted or rivetted joints, there is no need for pre-drilled holes in the SPR process which reduces production costs and time significantly. In addition, process control is well established for SPR which ensures the reproducibility of joint properties.

Fratini and Ruisi (2009) have presented the first application of the SPR technology to join FRP and metals. Different from the ductile deformation behaviour of metals, FRP materials generally exhibit a limited strain to failure, especially if epoxy resins are used as matrix materials. During the piercing of the FRP material, reinforcing fibres are cut and the complex stress state in the process zone induces further damage, e.g. matrix cracks or failure of the fibre-matrix interface. In addition to these intralaminar damage and failure phenomena, laminated composite materials are prone to interlaminar failure. These delaminations are caused by the bending deformation of the laminate and compressive in-plane stresses that result from the expansion of the rivet, Fig. 1.

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