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Development of a Tension Energy Absorber - Progressive Bearing Failure Mechanisms of Composite Bolted Joints

M. Waimer*) • P. Schatrow*) • T. Feser*) • H. Kraft*) • D. Kohlgrüber*)

*) *German Aerospace Center (DLR), Institute of Structures and Design, 70569 Stuttgart, Germany*

Abstract

This paper deals with experimental investigations on progressive bearing failure mechanisms of composite bolted joints and their integration into a crash design concept.

The objective of the presented test program is a crash design for a generic composite transport aircraft fuselage structure that utilizes tension loads in the passenger cross beam for energy absorption. In this design, the passenger cross beams are fabricated from carbon fiber reinforced plastics (CFRP) and kinetic energy shall be absorbed by progressive bearing failure of their bolted attachments.

A specific design for a standard bolted joint was developed and experimentally investigated, which provides controlled bearing failure to reliably ensure energy absorption in combination with sufficient structural integrity in a crash event. The concept ensures

- controlled direction of bearing failure under various loading conditions (on- and off-axis loading),
- a robust stop mechanism to limit the progressive bearing failure to a certain displacement,
- steady, progressive failure with non-constraining flow of the debris out of the local crush zone to prevent blockage effects, which may lead to abrupt load increase.

In a comprehensive test program on coupon level several design concepts were investigated under quasi-static loading considering the progressive failure mechanisms of one single bolt. This bolt connects two CFRP sheets and is set under regular conditions (pre-stressed). In the shear tests, the bolt shaft is pulled through one of the CFRP sheets leading to significant energy absorption.

Different design concepts, including specific notches and modified washers, were tested with the aim to ensure constant load level during the failure process by steady debris outflow that prevents debris blockage effects in the local crush zone in front of the bolt. Subsequently, preferential concepts were tested with a crash relevant dynamic loading rate of v = 2 m/s.

The concept was proven on element level using multi-bolt specimens (2-bolt and 4-bolt). On-axis and off-axis loading up to 30° was tested under dynamic loading conditions of v = 0.1 m/s and v = 2 m/s. Further design modifications were investigated that focused on enhanced robustness and an improved connection for the standard operating condition. On this element level, the concept feasibility could successfully be confirmed.

Finally, this paper presents application aspects of the tension absorber concept. Crash simulations of a fuselage section are presented that illustrate the potential of energy absorption by utilization of tensile crash loads in the passenger cross beam.

Keywords: transport aircraft · crashworthiness · composite material · bolted joint · bearing failure · progressive failure · energy absorption

M. Waimer(✉)
German Aerospace Center (DLR), Institute of Structures and Design, 70569 Stuttgart, Germany
e-mail: matthias.waimer@dlr.de / phone: +49 711 6862-648 / fax: +49 711 6862-227