Sensitivity analysis of numerical model of CFRP mechanical joint

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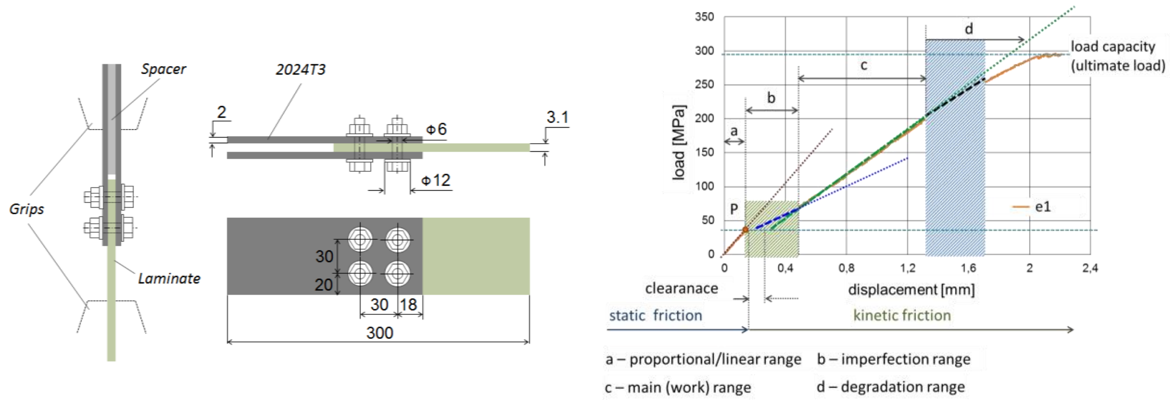
Abstract. The strength of mechanical joints is the weakness of laminates, therefore, mechanical joints require a special attention to be focused during both a designing and manufacturing process. The aim of the paper is to present sensitivity analysis of selected parameters on behavior mechanical joints in composite structure. Parameters of this analysis are divided into four groups: geometrical, stiffness, material failure and initial stress. Global stiffness and strength of laminate, different method of nut/bolt head modelling, residual stiffness, initial delamination and other parameters are taken into account. The composite specimen was made of quasi-isotropic CFRP laminate. The outer elements are made of 2024T3 aluminum alloy sheet, typically used in aircraft structures. Nonlinear finite element analysis of a metal-composite joint was performed using Newton-Raphson method with MSC. Marc code. Numerical and experimental results were compared. The sensitivity analysis of the numerical model on the aforementioned parameters is presented.

INTRODUCTION

Assembling and disassembling of any large constructions such as airliners are crucial stages of the manufacturing, service and repair processes. Mechanical joints allow disassembling and can be applied in rough conditions. High specific stiffness and strength of composite materials cause a mass reduction of a structure [1] and, consequently, a continuous increase in their usage in aircraft structures. Nowadays, large aircrafts are built in fifty percent of composites. However, the strength of mechanical joints is the weakness of laminates. In mechanical joints, stress concentration close to the holes in the connected parts occurs due to the notch effect and the point load (fastener action) transfer. In general, composites are brittle materials and are more notch sensitive than metal alloys. Therefore, mechanical joints of composite parts require a special attention during both the designing and manufacturing process. A numerical model is always an approximation of a real structure. Analysis of a nominal model (without imperfections) rarely leads to the same results as the ones obtained from the experimental tests.

OBJECT OF ANALYSIS

The analysis is performed on the specimen in the form of a double-shear bolted joint with four steel fasteners (Fig. 1a). The outer elements are made of 2024T3 aluminum alloy sheet and the inner element is made of quasi-isotropic CFRP laminate consisting of UD laminate layers (HTA/913) and external fabric layers (TR30S twill woven) with $[(0)/0/45/90/45/0/45/90/45/0/90]_S$ stacking sequence. The joint length L is 300 mm. The bolt diameter d is 6mm. A selected pitch length is 5d (30 mm) and the joint width is 70 mm (w = 70 mm). The aluminum alloy sheet thickness is 2 mm and the laminate thickness is 3.1 mm.



(a) (b)

FIGURE 1. Analyzed double-shear bolted joint: a) test scheme and specimen dimensions; b) selected experimental curve

Due to the joint symmetry, only a quarter of it was modelled. The left grip edge is fixed and the right grip edge is pulled. A segment to segment contact formulation was applied to matting surfaces of the specimen. Nonlinear analyses were carried out using Newton-Raphson method with Marc code. Simulation of a joint tension test was controlled with damage and failure criteria. The indices according to Hashin failure criterion were used to gradually reduce stiffness of the composite part. Aluminum alloy, used for the outer sheets, and steel, used for the bolt, are elasto-plastic materials. Material properties are presented in [2].

ANALYSIS OF MECHANICAL JOINT

The nominal model of a joint did not lead to results close to those obtained experimentally. The experimental curve was/were divided in four characteristic scopes (Fig. 1b).

Sensitivity analysis of a numerical model on parameters that potentially affect the behavior of a real mechanical joint was performed. These parameters were divided into four groups. A different method of nut/bolt head modelling, global laminate stiffness and strength components, residual stiffness, initial delamination and other modification of the joint model are taken into account.

The way the nut/bolt head (and washer) is modelled affects the load-displacement curve. In general, global changes of stiffness or strength components need to be abnormally high to cause significant changes in joint behavior. Initial delamination also does not affect the results in an extensive manner. The residual stiffness should be different in the bearing and net-tension area.

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