

Simulation of the Solid Rivet Installation Process

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Abstract

The riveting process with a solid rivet is one of the most applied joining processes in the aeronautic industry. New materials and new design requirements constitute challenges that drive the users to a better understanding of the installation process of riveted joints. Therefore, this study aims with the aid of FEM simulation to understand the phenomena occurring during the installation process and afterwards to predict the mechanical properties of the riveted joint depending on the installation parameters and characteristics of the adherends. The experimental installation process for the validation of the simulation model takes place in a fully automated C-frame riveting machine with all-electric drilling and riveting operations aptitude and continuous collection of process data.

This paper deals with the simulation of the installation process. The simulation model consists of a solid rivet with universal head described by the standard EN6081 and aluminum (2024-T351) adherends. The rivet material model has been obtained by a compression test performed on specimens prepared from fasteners. The effect of friction was studied and a suitable friction coefficient identified. The developed installation process model has been validated by comparing the simulation results with different experiments regarding the geometrical characteristics of the formed rivet head, the force-displacement curves and the surface residual strain of one adherend.

Afterwards, the clearance fit between the rivet shank and the borehole, the rivet grip, and the squeeze force have been numerically studied in order to determine their effect on the joint. The effect of these parameters on the riveted joint is evaluated considering the residual stress and the residual contact force. The simulation of plastic deformation and residual stress state caused by the installation process provides a basis for the prediction of the mechanical properties of the riveted joint under external forces which is subject to ongoing research.

Topic category: Automated Fastening / Simulation

Keywords

simulation, installation process, solid rivet, residual stress

1. Introduction

Riveting aluminum-alloy sheet material with solid rivets is the most applied mechanical joining process in the aircraft industry. Due to the increasing demands on prediction of the mechanical properties of such riveted joints, it is firstly necessary to understand the influence of the installation process on the quality of the riveted joint and to identify parameters that can affect it. Investigating riveted joints experimentally is expensive and time consuming. Using simulation methods is an alternative for such investigations.

Several researchers have used the finite element method to study the installation process of riveted joints and their mechanical characteristics. In most cases countersunk rivets were investigated. Müller [1] simulated the installation process of rivets with countersunk head using an axisymmetric finite element model to study the hole filling and radial expansion of rivets through the thickness of a joint mainly in terms of varying the squeeze force. Blanchot and Daidie [2] studied numerically the residual strain and stress. Kim and Park [3] investigated additionally to the formed rivet head geometry, the stress around the rivet hole and the effects of the interference fit in a 3D-simulation. Countersunk and universal rivets have been modelled three-dimensionally by Rans and coworkers [4]. The slug riveting process, which is quite similar to solid riveting, was studied numerically and experimentally by Coupard and Girot [5].

This paper deals with the investigation of the riveting process supported by experiments and numerical simulations. The study consists of two parts. The first part focuses on the

description of the riveting process and on the development and verification of the simulation model. A solid rivet with universal head fastening two aluminium plates is considered. The second focus is to identify numerically the influential parameters on the riveted joint with regard to the residual stress state and residual contact force.

In the course of this work special value shall be placed to a verification of the FE model. The usually referred characteristics like the geometry of the formed rivet head [3],[5] and the force-displacement progression of the squeezing process [3],[4],[5] shall be used. Since the residual stresses after the installation process influence the strength of the joint and are thus an important output of the simulation, the residual strains in the adherends shall also be used for verification. Rans et al. [4] used neutron diffraction to measure the strain within the adherends. This method is not chosen here because it requires a high effort and has a significant uncertainty. A strain measurement by strain gauges on top of the adherends was applied by Langrand et al. [6] who did not show a comparison between simulated and measured strains, however. Their experimental approach shall be used for verification of the model in this paper.

Although the friction has a large effect on the simulation results, this parameter has not received much attention in literature. In this study the influence of friction between tools, rivet and adherends will be numerically analysed and an attempt to determine the relevant friction coefficient by inverse identification from an experiment will be made.

2. Finite Element model

The model considers a solid rivet with universal head made of aluminum 7050 specified by the standard EN6081KE5 and two adherend sheets made of aluminum alloy 2024-T351 commonly used in aircraft industry. The rivet diameter is 4.0 mm, the grip length 11 mm, and the adherend thickness is 3 mm. The installation process takes place in 4 steps, clamping, drilling, squeezing and unclamping. The drilling process is not considered in this paper. During the clamping step, the upper (1) and lower adherend (2) are fixed by the upper and lower pressure foot (6+7), [Figure 1](#). The rivet is constrained by the upper die (5) for any translation in y-direction during the squeezing while the lower (4) die moves in y-direction against the rivet shank until the target squeeze force is achieved. The unclamping steps, in which all constraints and loads are removed, follows after the squeezing.

A two-dimensional axisymmetric model consisting of one rivet, two adherends and the installation tools is shown in [Figure 2](#). The simulations are carried out using the FE-program ABAQUS/Explicit.

· Element type and mesh section

The riveting tools are implemented as rigid bodies. Four node elements with reduced integration have been chosen to model

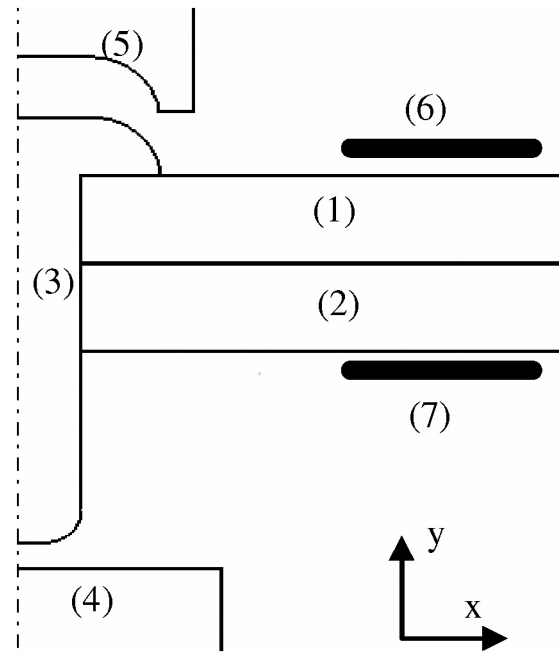


Figure 1. Riveting process configuration

rivet and adherends. In a preliminary numerical study an optimal element size (0.05 mm in the rivet and around the borehole and 0.15 mm in the remaining parts) and mass scaling have been determined. The mass of the critical elements, which could raise the critical time increment, was scaled once at the beginning of every simulation step to achieve a prescribed element stable time increment of 0.3 μ s. Arbitrary Lagrangian Eulerian (ALE) adaptive meshing of the collar with a frequency of 10 and one remeshing sweep per increment was specified during the squeezing to optimize element distortion. This makes it possible to maintain high mesh quality during the forming despite of high strains.

· Material model

Rivet and adherend material are both described by isotropic elastic-plastic behaviour. The mechanical properties of the adherend material have been obtained from the literature [6]. Data of the plastic hardening curve of the rivet material have been obtained by a compression test performed on specimens prepared from the rivet considered in the model. The determination of this data is not topic of the current paper.

· Boundary and contact conditions

The clamping unit ((6) and (7) in [Figure 1](#)) and the lower die (4) are constrained against translation in x-direction and rotation around the y-axis while the upper die is completely constrained and the adherends are unconstrained, see [Figure 2](#). A symmetry boundary condition is applied to the rivet. A clamping force $f_c = 3.5$ kN is applied to the pressure feet. A squeeze force f_{sq} is applied to the lower die during the squeezing step as shown in [Figure 2](#). Its amplitude curve is smoothed at the beginning and the end of the step.

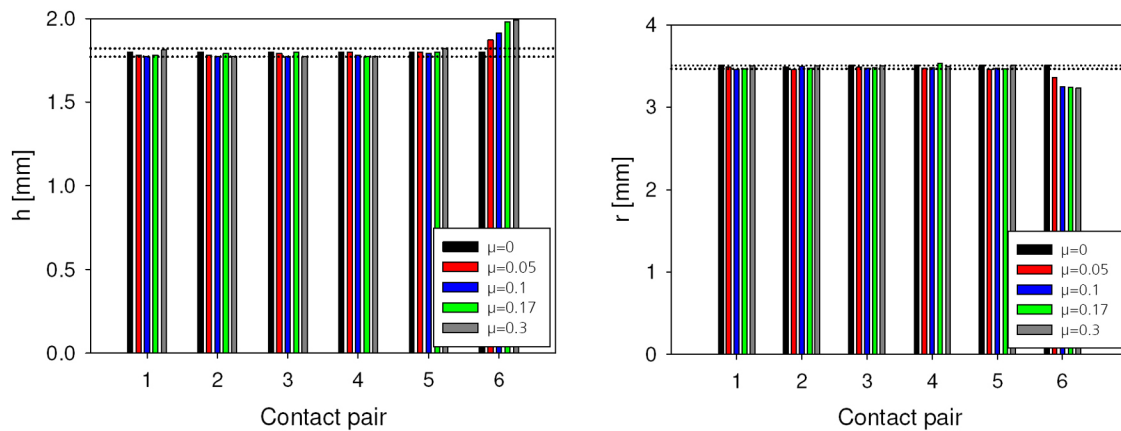


Figure 4. Influence of friction coefficient on geometrical characteristics of formed rivet head

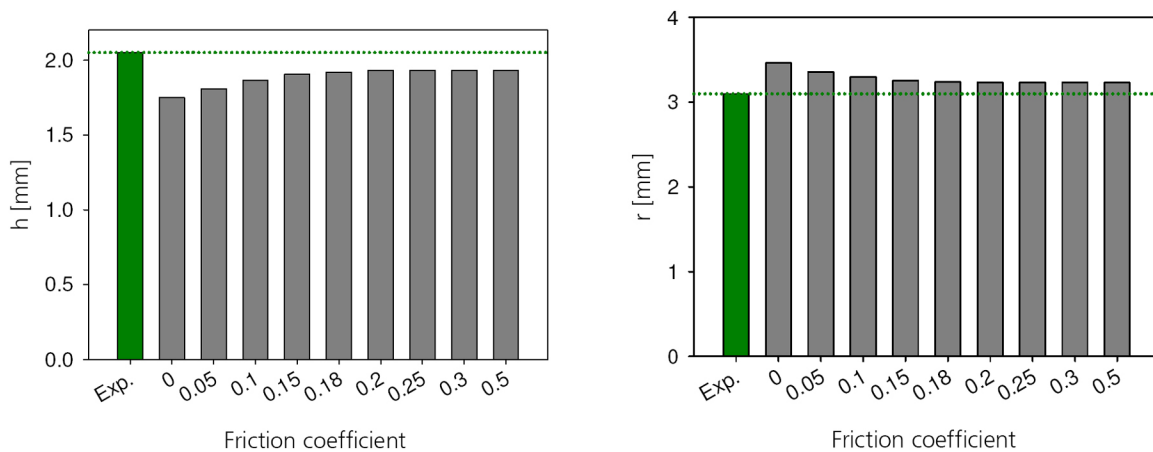


Figure 5. Influence of friction in contact area 6 on geometry of formed rivet head

3. Experimental validation

Experimental investigations have been performed in order to validate the simulation results. The force-displacement curve, the geometrical characteristic of the formed rivet head, the contact pressure between the adherends, and the strain on the adherends top side are characteristic that have been considered.

3.1. Experimental equipment

The experiments for the verification of the simulation model were performed in a fully automated C-frame riveting machine (see Figure 6) with all-electric drilling and riveting operation skills for one and two-pieces fastener like solid rivet, lockbolt stump type and Hi-Lite. All relevant process data occurred during the installation process were registered and stored by the control unit of the machine. The machine is fitted with two high-speed cameras to observe the installation process.

3.2. Force-displacement

The force-displacement curve of the squeeze tool during the installation is one of the main verification characteristics used in this study. The model configuration described in paragraph 2 was used varying the rivet diameter 4.0 mm to 4.8 mm.



Figure 6. The riveting machine

The simulation results match the experiments very well, see Figure 7.

3.3. Geometrical characteristics of formed rivet head

Width and height of the formed rivet head have been considered varying the squeeze force and the rivet diameter. The results of simulations and experiments show good agreement, see Figure 8.