Simulation of self-piercing riveting processes

Self-piercing riveting

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Self-piercing riveting

Overview

• The self piercing riveting process
• FE analysis of the joining process
  – Large deformation
  – Material failure
  – 2D remeshing approach
  – 3D remeshing approach
• Comparison with experiments
• Process optimization with FEA
• Summary
Self-piercing riveting

- Self-piercing riveting is a forming process for joining sheets.
  - A rivet joins two or more blanks.
  - Similar to clinch processes (does not use a rivet)
- Alternative to welding and bonding.
  - Combination with bonding: advantages of both joining techniques
- Several advantages compared to (spot) welding:
  - No change of material properties due to heat (micro structure change)
  - Improved fatigue
  - Coated/painted blanks can be joined.
  - Different materials can be joined (aluminium and steel, ...)
  - Reduced deformation due to thermal stress and strain
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Self-piercing riveting
The joining process

Tool Setup

- Punch
- Rivet
- Blankholder
- Upper sheet
- Lower sheet
- Die

Force / Displacement
Force
Self piercing riveting
The joining process stages
Simulation of self-piercing riveting processes

Self piercing riveting
The joining process stages
Simulation of self-piercing riveting processes

The finite element model

- Explicit analysis (LS-DYNA)
- Axisymmetric model
- Rigid tools
  - Prescribed motion for punch
  - Blankholder force
- Reduction of analysis time: sheet is modelled according to die diameter
  - Displacement boundary conditions in radial direction at sheet outer diameter
- Two analysis approaches have been used, 2D remeshing and 3D ALE.
- Both use the same element sizes in the region of interest.

Elements with eff. plastic strain from 0 % to 0.1 %
The self piercing riveting FE analysis has to capture:
1. Large deformation (may cause element distortion).
2. Material failure, the upper blank has to be divided into two regions.
Large deformation may be accounted for by remeshing or ALE analysis.

- **Remeshing:**
  A new mesh is generated during the analysis. The results are mapped from the old mesh to the new one (Lagrange method).

- **ALE (Arbitrary Lagrangian Eulerian):**
  The material flows through a mesh which is fixed in space (Euler method).
Remeshing only for the upper blank.
The finite element model
3D ALE model

ALE for the upper blank only.
2° section modelled.
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The finite element model
Large deformation and material failure

- Material failure requires failure criteria. A sophisticated criterion is difficult to obtain and requires experimental data.
- Instead a minimal thickness is used (geometric criteria). If the upper sheet's thickness drops below a certain value, the mesh is divided into two regions.
- This can be done in two ways for remeshing:
  - The analysis is stopped and an element is deleted during a small restart.
  - LS-DYNA option
    *PART_ADAPTIVE_FAILURE

- ALE does not require a special failure criteria, separation of material is treated automatically.
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The finite element model
Material failure

Finite element mesh before and after manual element deletion.
*PART_ADAPTIVE_FAILURE is a special option for remeshing analysis. Disadvantage: The mesh is split only once.
- If material has to remain below the rivet shank, element distortion will occur at the second splitting location.
At the second splitting location high eff. plastic strain occurs
- An additional criteria was used in conjunction with *PART_ADAPTIVE_FAILURE: failure based on eff. plastic strain
- Disadvantage: criteria may delete several elements below the rivet shank
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The finite element model

Material failure

*PART_ADAPTIVE_FAILURE with eff. plastic strain failure
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Two verification processes
Process parameters

Two processes have been analysed.
First process:
- upper sheet H340LA, 1.5 mm
- Lower sheet H340LA, 1.5 mm

Second process:
- Upper sheet AA6181, 1.5 mm
- Lower sheet AA6181, 1.5 mm

Blankholder force 4.56 kN

Process parameters:
- Coulomb friction coefficient 0.1

Stress-strain curves for St (A), Al (C) and rivet (B and D) with extrapolation
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Two verification processes
Steel sheet results

Result of 2D analysis with adaptive_failure option

Result of 2D analysis with manual element deletion
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Two verification processes
Steel sheet results

Result of 2D analysis with adaptive_failure option

Result of 2D remeshing analysis with reduced rivet strength
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Two verification processes
Steel sheet results

Result of 2D analysis with adaptive_failure option

Result of 3D analysis
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Two verification processes
Aluminium sheet results

Result of 3D analysis with reduced rivet strength

Result of 2D analysis with adaptive_failure option and reduced rivet strength
Al process: Force-displacement curve
A- remeshing
B- ALE

Note: process ends at 5 mm
Simulation of self-piercing riveting processes

Two verification processes
Forces

St process: Force-displacement curve
A- original hardening curve for rivet
B- reduced hardening

Note: process ends at 5 mm
Two verification processes

Summary

Comparison of analysis:
- ALE requires twice the analysis time compared to remeshing.
- Remeshing results are closer to experiment.

Note: the ALE model is not finally checked regarding contact stiffness, mesh density, element quality and several minor numerical items.
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FE analysis for process optimization

Results that can be derived from process simulation:
- Rivet deformation like undercut
- Blank deformation and die filling
- Work hardening of blanks and rivet
- Stress in rivet and blank
- Tool forces
- Springback
- Initialization for pull-out analysis
- Initialization for fatigue analysis
Conclusions:
- ALE and remeshing may be used to analyse self piercing riveting.
- Both analysis techniques are stable.
- Typical analysis will use remeshing.
- Yet, remeshing is more accurate. 3D ALE analysis technique has to be improved.
- If 3D effects have to be taken into account (e.g. off-axis loading), the 3D ALE analysis may be applied.
- Extrapolation of material properties is important. Other analysis (here not shown) indicate that they have a major impact compared to process parameters like friction.
- If self piercing riveting can be analysed, similar processes (e.g. clinching) and other rivet joints may be analyzed, too.
Summary

Future work:
- Improvement of ALE analysis.
- Analysis of pull-out forces for crash analysis
  - Requires 3D models
  - Mapping procedure from 2D to 3D needed
- Some processes result in major element deformation in lower blank. Remeshing or EFG (Element Free Galerkin) may be taken into account.
- Validation of material properties for sheets and rivet.
- Validation of process parameters, (friction, ...)

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Thank you very much for your attention!

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