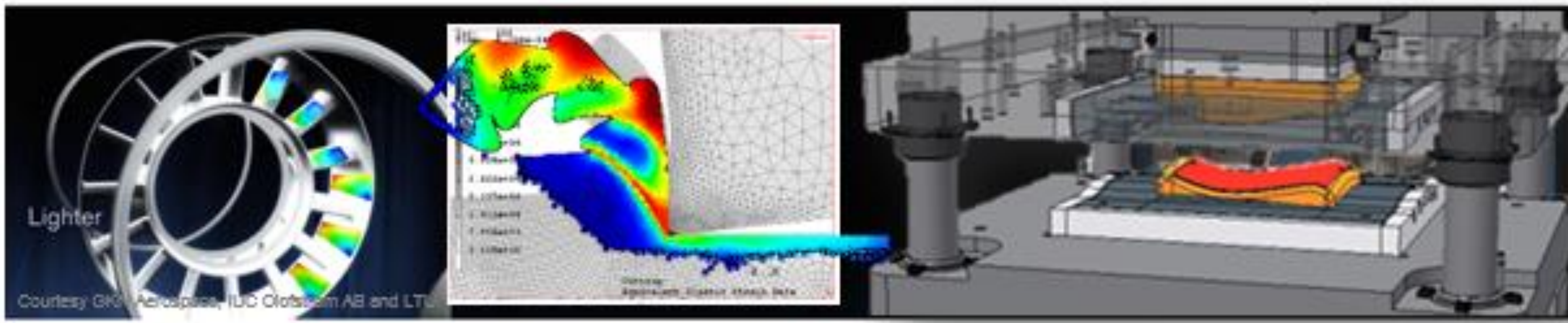
Third International Workshop on Validation of Computational Mechanics Models

Virtual process chain for superalloy & titanium sheet metal aero engine structures

Validation and demonstrators



Eva-Lis Odenberger PhD

Industrial Development Centre in Olofström AB

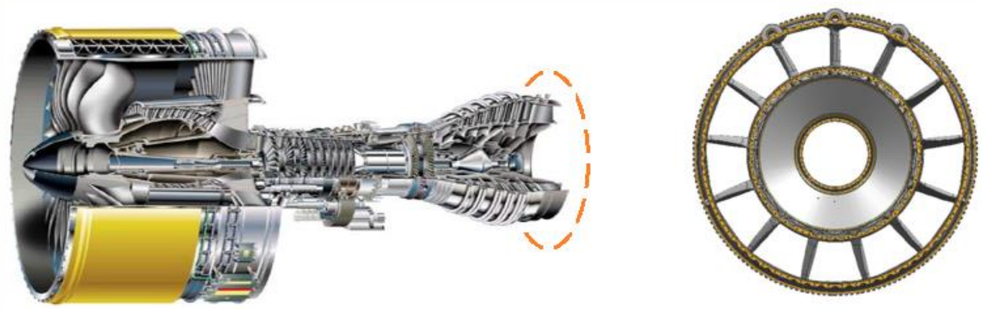
Adj. Senior University Lecturer, Solid Mechanics, Luleå University of Technology

Agenda

- Background and research targets
- Material characterization and model calibration procedures
- Titanium and nickel-based superalloy forming
- Examples of FE-modeling and demonstrators:
    - Forming, trimming and springback
    - Welding and compensation procedures
- Discussion

Background

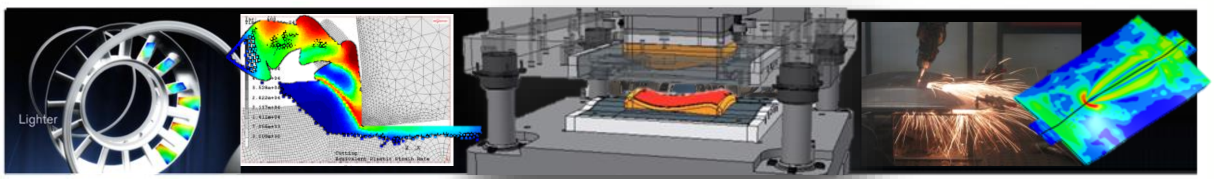
- The European aero engine industry focus on alternative manufacturing methods for load carrying structures in titanium and nickel based super alloys
  - Traditionally consisting of large-scale single castings
  - Fabrication - involves sheet metal parts, small ingots and simple forgings assembled by welding
    - to decrease weight and thereby fuel consumption
    - to reduce product cost and increase the in-house level of processing



Load carrying 718 structure in the rear part of the GP7000 TEC engine.

Background and research targets

- Use FE modeling to suggest and evaluate competitive forming procedures, welding and machining strategies, heat treatment methods
- Challenge is to accurately predict and compensate the tooling for springback and shape distortions which occur in the fabrication chain
- GKN Aerospace desire titanium and superalloy sheet metal parts together with FE-results for subsequent manufacturing analysis
- Search for new regional sub-suppliers who can provide GKN Aerospace Sweden with parts and an increased insight into the different forming procedures
- Funding from VINNOVA, Swedish Governmental Agency for Innovation Systems, NFFP 4, 5, 6 SME, SNSB NRFP SME



Courtecy GKN Aerospace, IUC Olofström, LTU and DYNAmore nordic

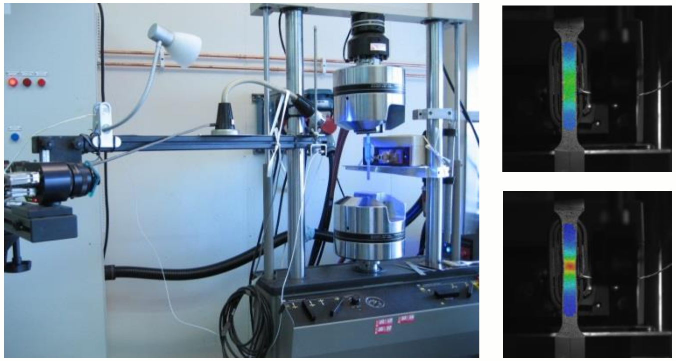
Research targets

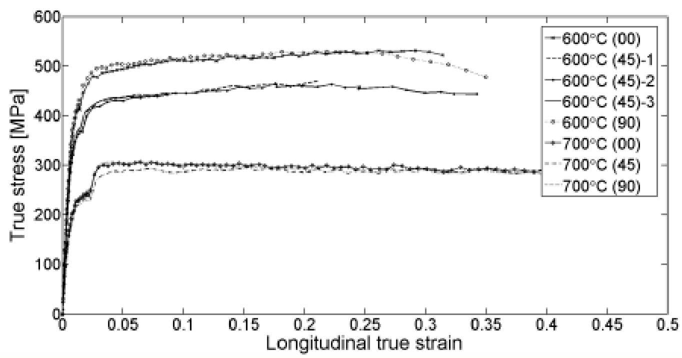
- **Experimental studies**
  - Characterize thin metal sheets of Haynes®282, Alloy718 and Ti-6Al-4V
    - Thermo-mechanical properties in a format suitable for FE-analysis
    - Damage and fracture
    - Cold and hot forming tests to produce geometries of commercial interest. Purpose to compare predicted and measured responces
- **Numerical studies** (FE-modeling in LS-DYNA)
  - Aim is to predict and suggest competitive cold and hot forming procedures with high accuracy
    - Invers modeling to evaluate material tests and identify material model parameters – hardening, anisotropic yield criteria, stress relaxation
    - Study damage and fracture based on the GISSMO model in LS-DYNA
    - FE-modeling of a forming procedure to provide with results for subsequent welding analyses
    - Compensation of forming tools for both springback and welding shape distortions

Thermo-mechanical material characterization

- Reference data for material model calibration and forming FE-analysis
  - Uniaxial tensile and compression tests
  - Biaxial tests, cyclic tests, forming limit tests, process parameter tests
  - Shear tests for calibration for damage and failure models
  - Creep and stress relaxation tests in collaboration with LTU and GKN

Uniaxial tensile test at elevated temperatures using ARAMIS™





Thermo-mechanical material characterization

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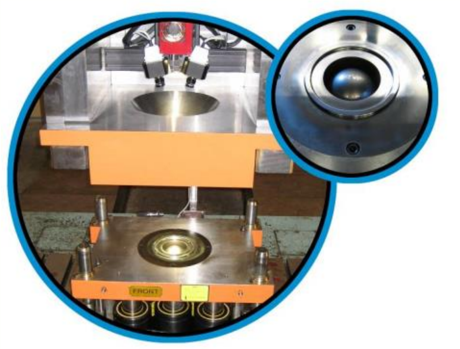
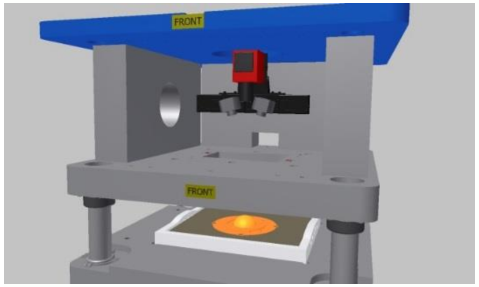
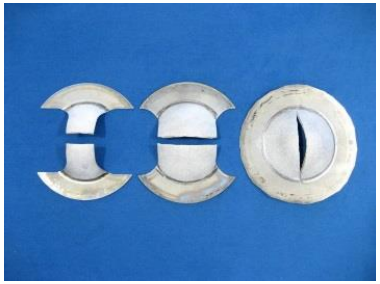
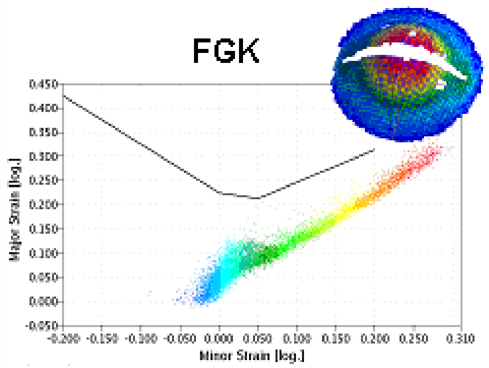
Biaxial test at elevated temperatures using ARAMIS™, Viscous Bulge and FLC tests





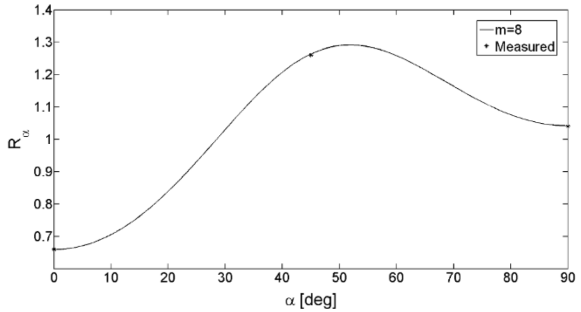




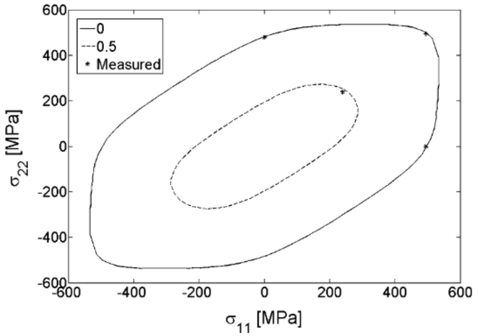
Material model calibration

- The forming procedures are analyzed using the YLD2000 material model in LS-DYNA

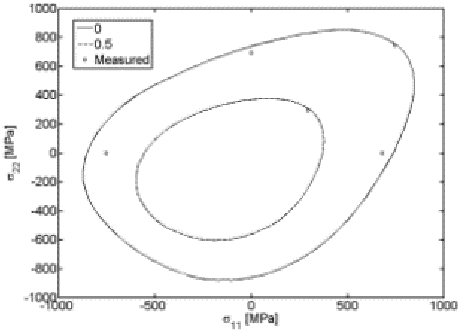
Calibrated Barlat et al. (2003) yield surface and R-values for alloy 718.



Titanium: anisotropic yield criteria, Barlat et al. (2003)



Cazacu et al. (2006)

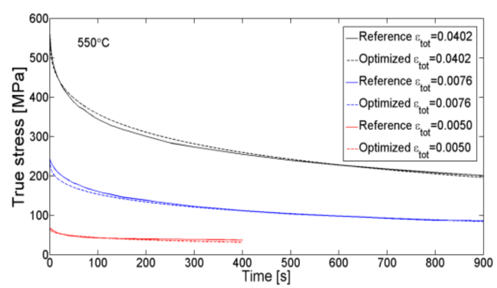


Material model calibration

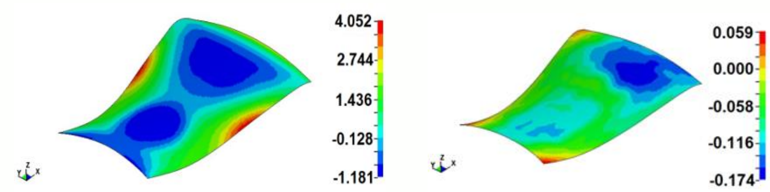
- Stress relaxation described using e.g. a Zener-Wert-Avrami formulation

$$\sigma = \sigma_0 exp(-At)^m \; ; \qquad A = Bexp\left(-\frac{\Delta H}{kT}\right)$$

Stress relaxation modelling and tests in collaboration with LTU/GKN

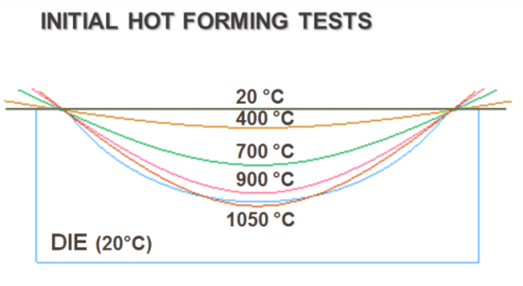


Part deviation after forming (left) and hot sizing (right), [mm]



Titanium and superalloy forming in fabricated aero engine structures

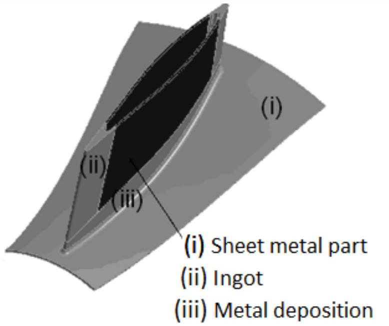
- Springback is extensive upon forming thin metal sheets, scattering behavior cause difficulties
- Ti-alloys such as Ti-6Al-4V are often formed at elevated temperatures multistage forming with intermediate annealing or a final hot sizing operation
- Super plastic forming (SPF) for complex geometries
- Nickelbased superalloys require a high degree of straining when formed
- Time and material consuming processes

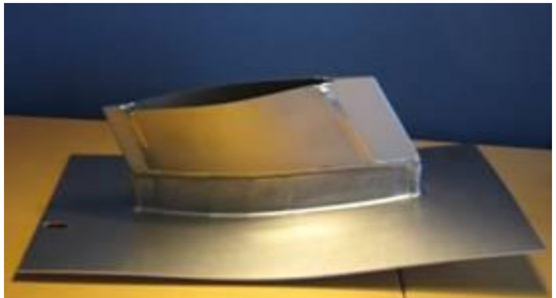


Shape deviation

Demonstrator - forming, trimming and springback

- Studies to perform single stage forming with focus on short cycle times
- Forming at temperatures up to 950°C, models with different level of complexity
- Virtual tool development to keep the manual die tryout at a minimum
- Three different components produced to evaluate the applicability of chosen methods and models

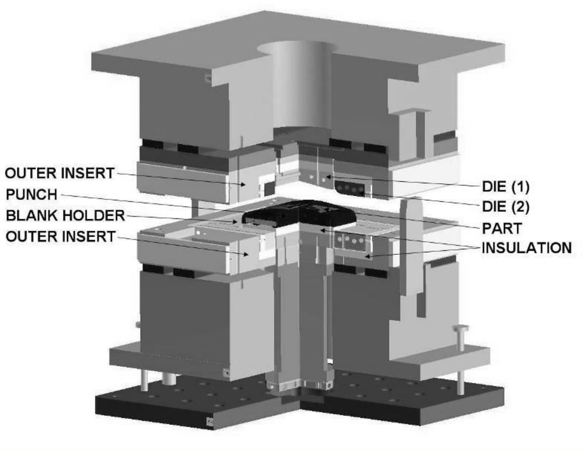


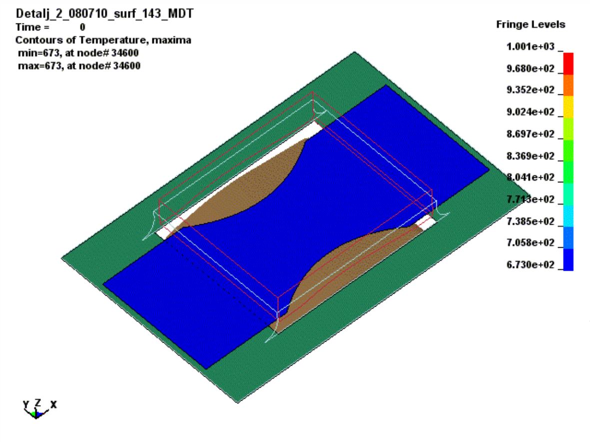


Courtesy GKN Aerospace

Demonstrator - forming, trimming and springback

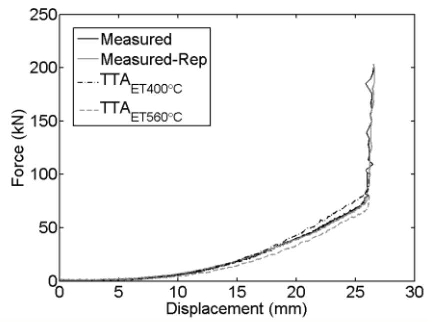
- Titanium thermo-mechanical forming procedures, academic tool concepts
- Careful modeling of the forming tests to insure consistent tooling geometries and conditions
- Correlation between predicted and measured responses, forming temperatures up to 550 ℃





Draw-in [mm]

Location	Predicted	Measured
y_1	0.55	0.5
y_2	0.76	0.9



Demonstrator - forming, trimming and springback

- Titanium thermo-mechanical forming procedures, academic tool concepts
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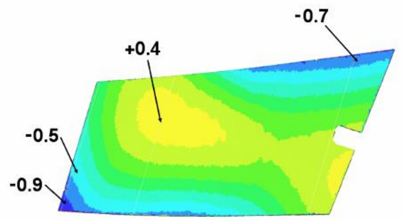
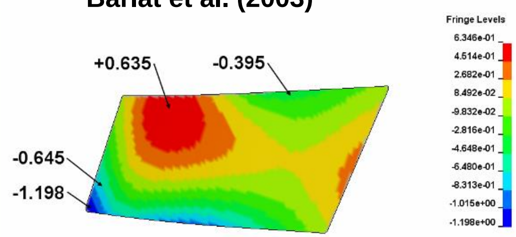
Measured shape deviation [mm]

Predicted shape deviation [mm]

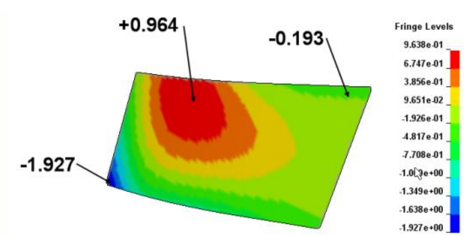
Titanium part geometry 1



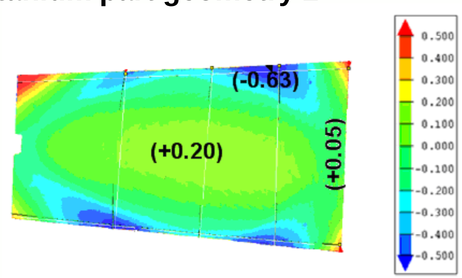
Barlat et al. (2003)



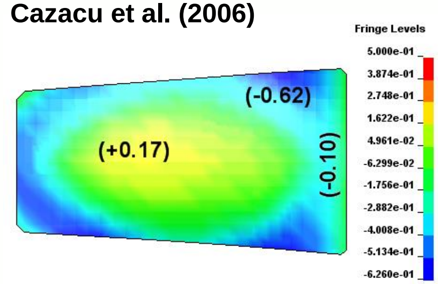
Isotropic assumption



Titanium part geometry 2



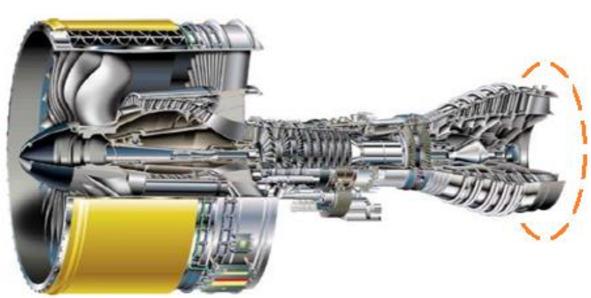
Cazacu et al. (2006)



Demonstrator - forming, welding and compensation

Target in this work is to propose a methodology for compensation of accumulated forming, welding and heat treatment distortions using LS-DYNA. To provide for this it is necessary to use different solvers, coupled simulations and element types. The methodology involves:

- FE-modelling of forming and cutting in the anisotropic nickel-based superalloy 718
- Mapping of results from FE forming shell mesh to FE welding and heat treatment solid mesh, springback analysis
- FE-modelling of welding, cooling and springback
- Compensation of the forming tools for the accumulated shape distortion



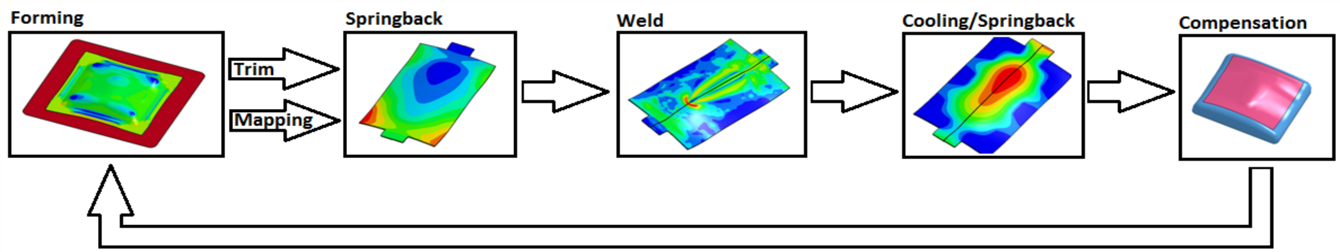
Project partners:

GKN AEROSPACE · IUC Industriellt Utvecklingscentrum Olofström · Olofström School of Automotive Stamping · Luleå University of Technology · Acoustic Agree · ITE · DYNA More Nordic

Simulation of the manufacturing process chain

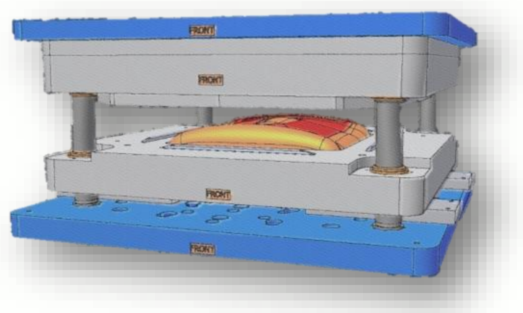
The simulation of the manufacturing process of these parts will require a variety of different solvers and element types.

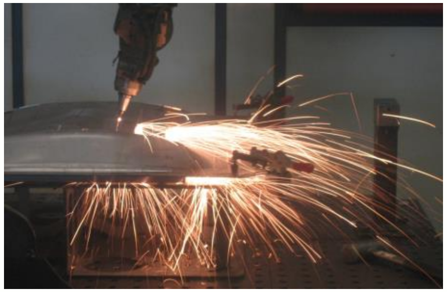
- The forming simulation is done using the explicit solver with shell elements for simulation time reasons. The part is trimmed at the end of the forming stage which is not possible using solid elements.
- The welding simulations are preferably performed using solid elements and the implicit solver. It will also require a thermo-mechanical coupling to account for the temperature dependent material properties.
- The mesh used in the forming simulation will differ substantially from the mesh used in the welding simulations. Mapping between different meshes and mesh types are necessary.

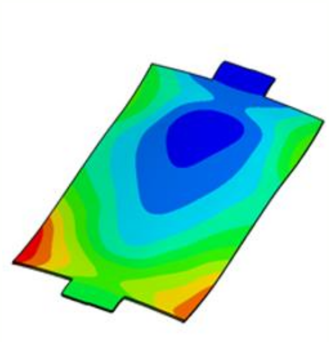


Simulation of the manufacturing process chain

The forming and trimming procedures is analyzed using the YLD2000 material model in LS-DYNA and fully integrated shell elements

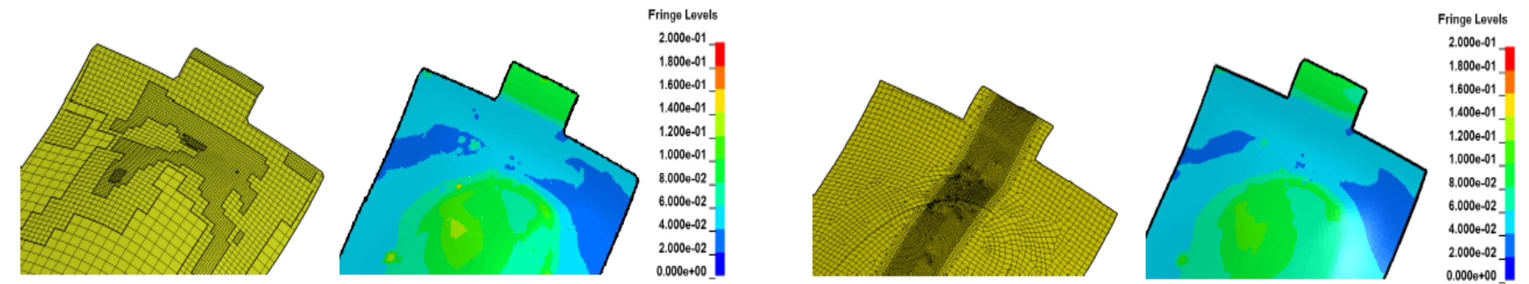






Mapping of results from forming shell FE-mesh using adaptivity to the fully integrated solid welding FE-mesh. The novel shell to solid mapping functionality in LS-PREPOST v4.2 is used.

The mapping algorithm is divided into a through thickness and an in-plane part.



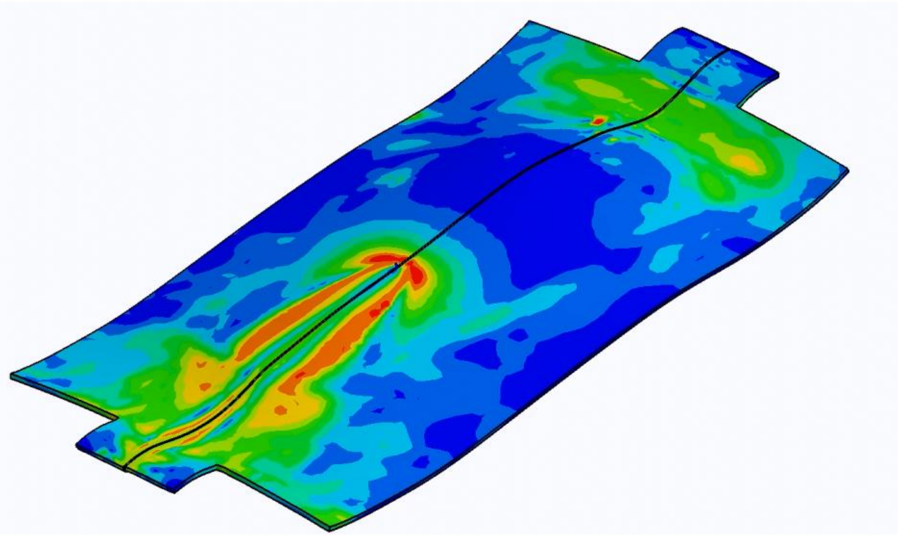
Forming simulation mesh (left) and welding simulation mesh (right) with mapping.

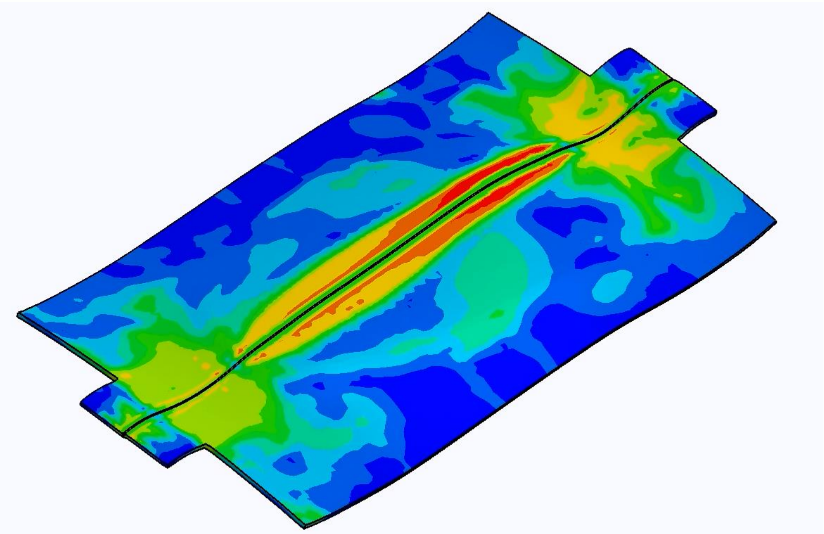
Simulation of the manufacturing process chain

The welding simulation is performed using *MAT_CWM material model

- The CWM has a number of features that enables welding simulations.
    - The elements can be either material or ghost. Ghost material is used for the weld filler material that is added to the weld seam. The ghost material is given silent properties used until the material is activated
    - MAT_CWM has anneal functionality. Above a user-specified temperature, the history variables such as effective plastic strain and/or backstress are zeroed out - material properties are reset to virgin.
    - Linear isotropic/kinematic hardening and it is based on von Mises yield criterion where all material properties are temperature dependent.
- The weld heat source heats up the material above the melting point, it is activated and given properties of the base material of that temperature.
- Above the annealing temperature, the history variables are zeroed out and the material properties are reset to virgin. The material will behave as ideal plastic without evolution of the plastic strain or backstress variables.

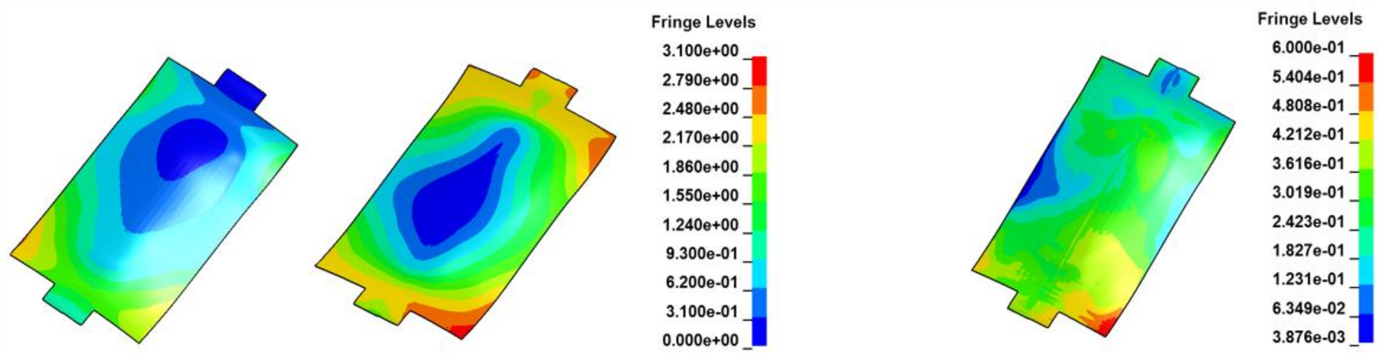
Simulation of the manufacturing process chain





Simulation of the manufacturing process chain

- The welded part is transferred to a cooling simulation using automatic thermal and mechanical timestepping for simulation time efficiency.
- It is assumed that the part is kept in the welding fixture during cooling.
- The last process stage is a springback step where the elastic stresses are released and the final part geometry is received.
- The compensation is accomplished using *INTERFACE_COMPENSATION_NEW



Part deviation after forming (left), welding (middle) and compensation (right), [mm]

Simulation of residual deformation from a forming and welding process using LS-DYNA®, Mikael Schill, Eva-Lis Odenberger, 13th International LS-DYNA Users Conference

Thank you for the attention!

Eva-Lis Odenberger PhD
Adjunct Senior University Lecturer, Solid Mechanics
Mechanics of Solid Materials, Luleå University of Technology

Industrial Development Centre in Olofström AB/Forming Group OSAS
Address Vällaregatan 30, SE-293 38 Olofström
Phone 0454-975 00 **Fax** 0454-921 21 **Direct** 0454-975 45 **Mobile** 0768-99 75 45
E-mail eva-lis.odenberger@iuc-olofstrom.se **Web** www.iuc-olofstrom.se