Marie Skłodowska-Curie Actions
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AdMoRe project

Influence of the residual stresses in reshaping operations of large aeronautical parts

Ramiro MENA
AIRBUS
École Centrale de Nantes (ECN)
Universitat Politécnica de Catalunya (UPC)

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Motivation of the project

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Context
Large and thick aeronautical parts present distortion after machining because the residual stresses (RS) generated during previous manufacturing steps (heat treatment).

Before assembly, distortion is removed manually.

It is a time consuming operation and depends exclusively on the skills of a well trained operator.

Scientific goals
To develop a Reduced Order Model (ROM) for reshaping
To evaluate the main parameters during the process and its uncertainty level

Industrial goals
To study reshaping from a numerical perspective
To adapt reshaping simulations to each warped geometry
To introduce numerical simulation in order to assist the operator

Residual Stresses

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Definition
"Residual Stresses in a body are those which are not necessary to maintain equilibrium between the body and its environment" (Whiters and Bhadeshia, 2001)

Types
Type I: Macrostresses (our goal)
Type II: Intergranular stresses
Type III: Atomic scale

Formulation

$$\boldsymbol{\sigma} = \boldsymbol{\sigma}^r + \boldsymbol{\sigma}^l$$
$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}^r + \boldsymbol{\varepsilon}^l \qquad \textbf{(1)}$$

$$\boldsymbol{\sigma}^r = \mathbf{D}\cdot\left(\boldsymbol{\varepsilon}^r - \boldsymbol{\varepsilon}^0\right)$$
$$\boldsymbol{\varepsilon}^r = \boldsymbol{\varepsilon}^0 + \boldsymbol{\varepsilon}^0_r \qquad \textbf{(2)}$$
$$= \boldsymbol{\varepsilon}^0 + \mathbf{C}\cdot\boldsymbol{\sigma}^r, \mathbf{C} = \mathbf{D}^{-1}$$

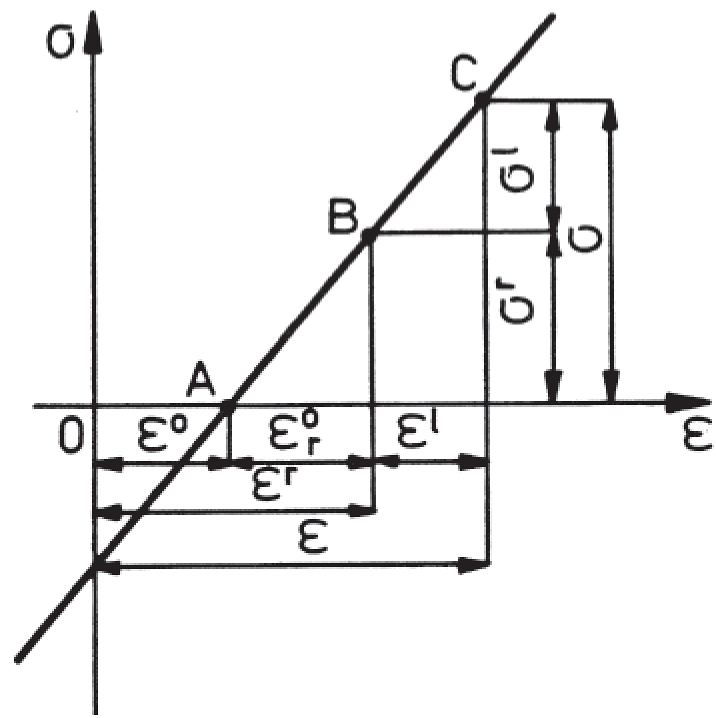

Fig. Strain and stress decomposition with initial prestrain
(J. Holnieki-Szule and Z. Mroz, 1897)

Distortion: How it is produced (1/4)

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Problem statement

What? To produce <u>numerically distortion</u> and to study reshaping

Research question

What is the influence of RS for reshaping ?

- RS order of magnitude: ±30 MPa (Robinson et al., 2014)
- for simple geometries (e.g rectangular plates)

Proposal :

To compare a deformed part with and without RS

- Geometry : T shaped beam
- Reshaping : four point bending operation
- Material : AA7010

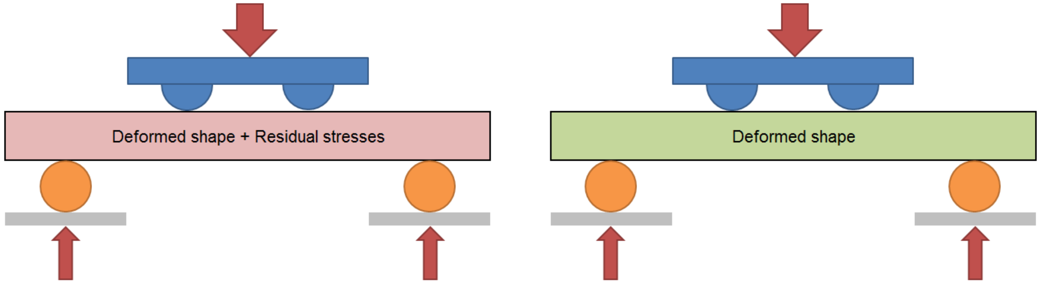

Fig. Four point bending test scheme

Distortion: How it is produced (2/4)

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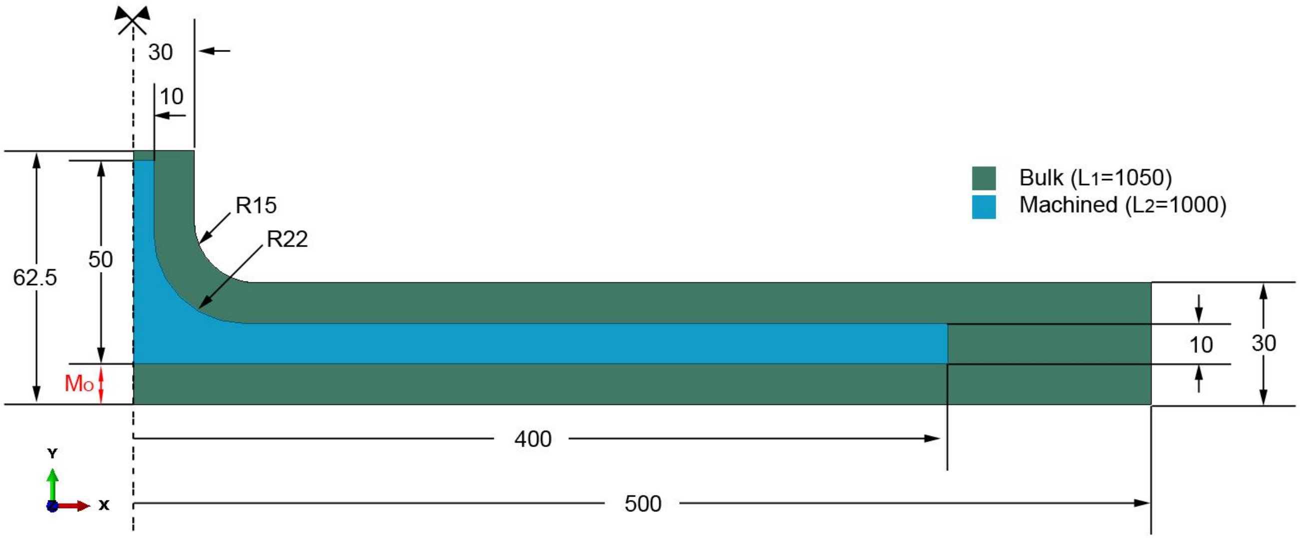
Methodology

What? To produce <u>numerically distortion</u> and to study reshaping

How? To simulate all the manufacturing chain.

- Two study cases: Mo=10 and 5mm (Machining offset Mo)



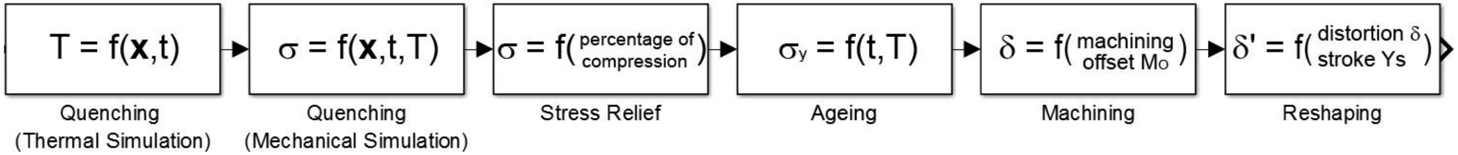


Fig. T-shaped beam geometry (top). Sequential simulation approach (bottom)

Distortion: How it is produced (3/4)

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Residual stress evolution

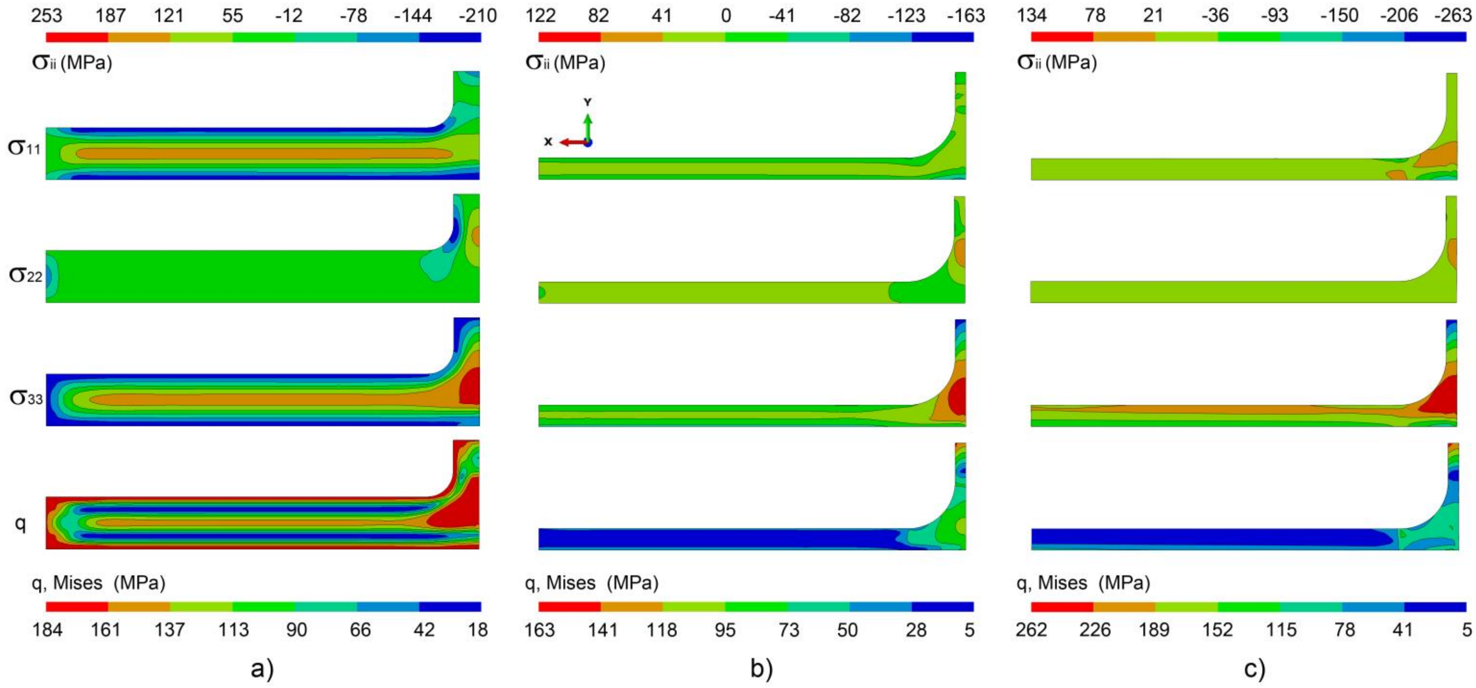

Fig. RS evolution during a) Quenching (σ_{y1}=162 MPa). b) Machining: case 1 and c) Machining: case 2 (σ_{y2}=390 MPa). Note : The snapshots are taken in plane Z=0 and presented in the undeformed configuration

Distortion: How it is produced (4/4)

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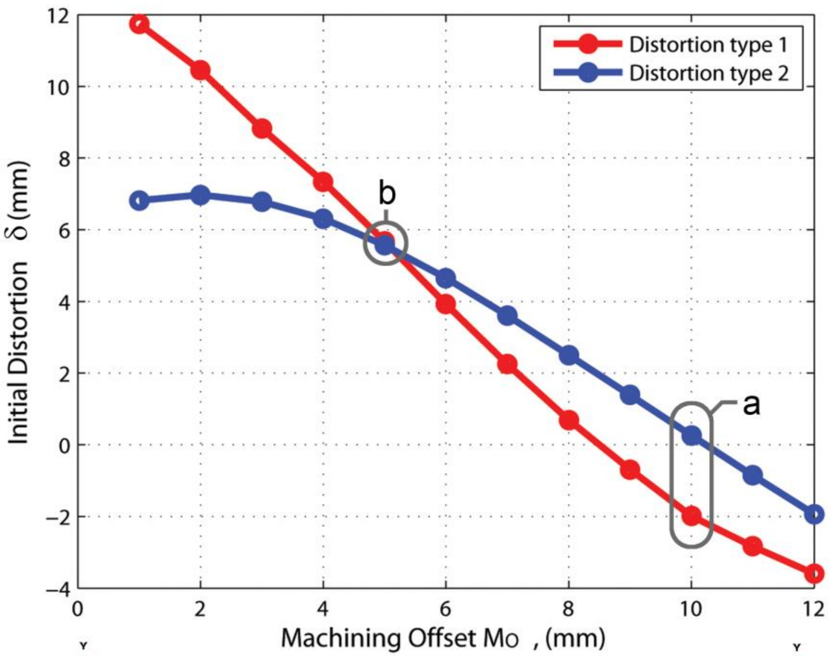
Warped geometry
Distortion δ as a function of RS and machining offset (Mo)
$\delta = f(RS,Mo)$

Type 1 (Longitudinal)
Type 2 (Wings closure)



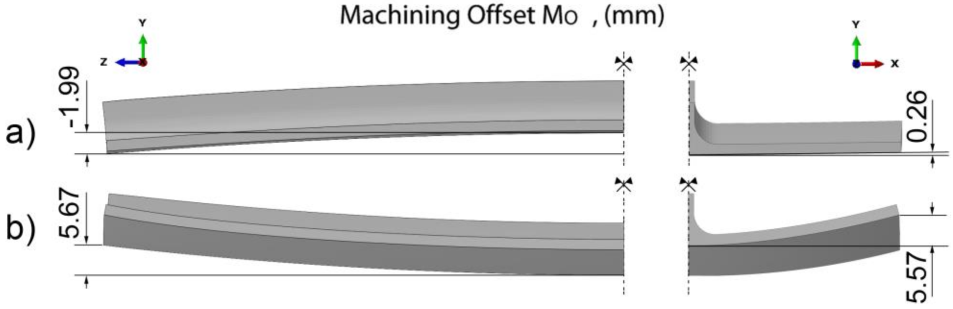


Fig.
Distortion δ as a function of Machining offset (Mo)
a) δ type 1 and 2 for Mo=10mm
b) δ type 1 and 2 for Mo= 5mm

Reshaping: Influence of RS (1/3)

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Reshaping

Two study groups :

- Beam with Residual Stresses (RS)
- Beam without Residual Stress (RSF)

Three configurations for each machining case

Machining Offset Mo(mm)	10			5		
Position ID	P1	P2	P3	P4	P5	P6
Top (mm)	150	300	150	425	425	300
Bottom (mm)	425	425	300	150	300	150

Contact : Rigid supports with friction μ=0.05 (Koc et al., 2006)

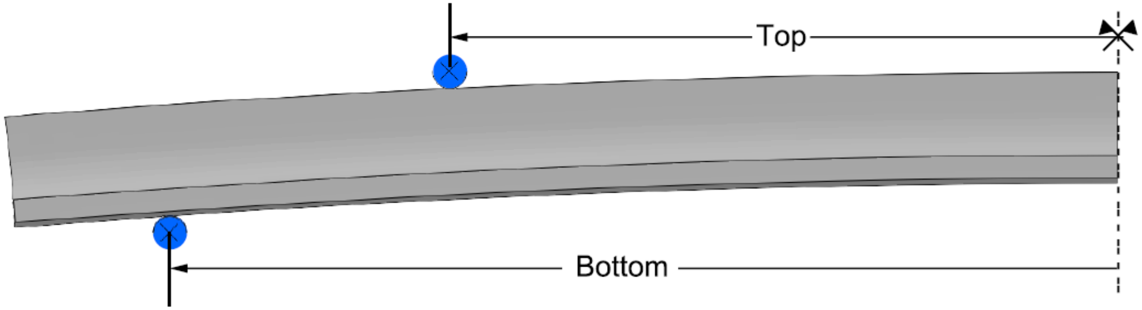

Fig. Reshaping setup. Location of top and bottom supports

Reshaping: Influence of RS (2/3)

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Comments

Reshaping as an optimization problem
Each position presents its own optimum stroke Ys where δ is minimized.
There is an offset between the RS and RSF system.
A geometrical tolerance is required to validate possible configurations
Distortion can be minimized but not totally removed

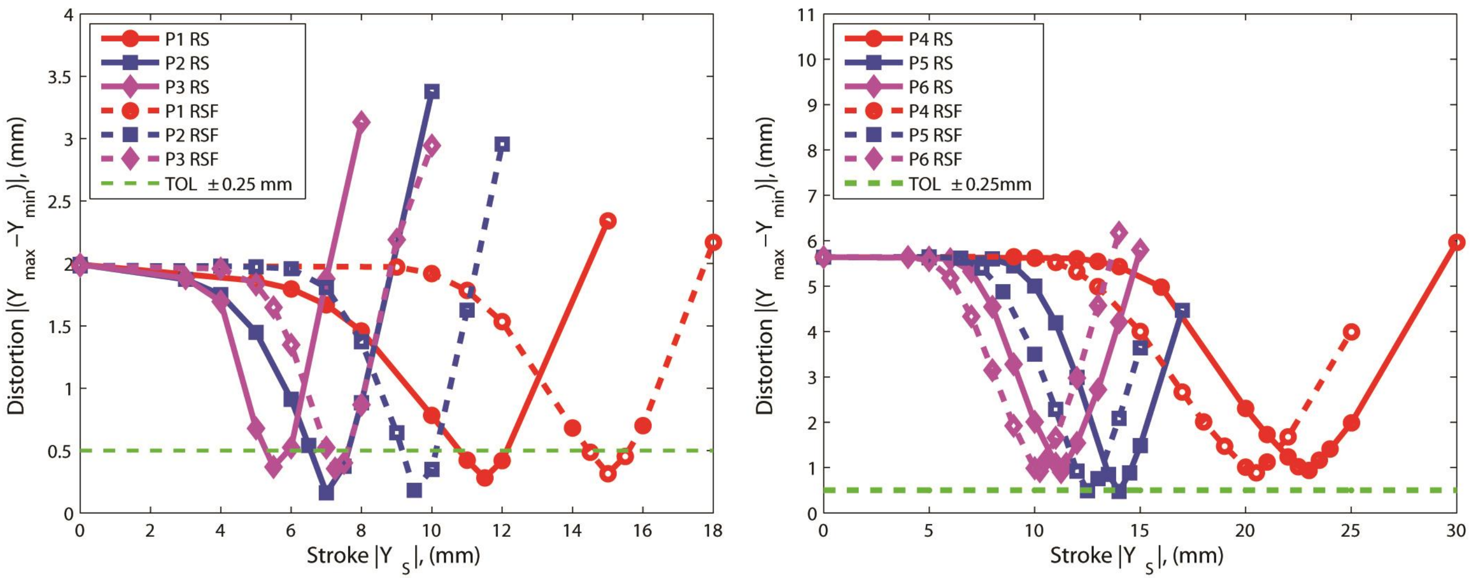

Fig. Distortion evolution as a function of the given stroke Ys. Left) Mo=10mm and Right) Mo=5mm

Reshaping: Influence of RS (3/3)

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RS vs RSF system : distortion level

RSF hypothesis is able to mimic the distortion evolution of RS system.

Initial distortion measurement of the whole system is the key.

(+) Variability between two different pieces will be collected in the deformed shape.

(-) A calibration step will be required to determine the offset.

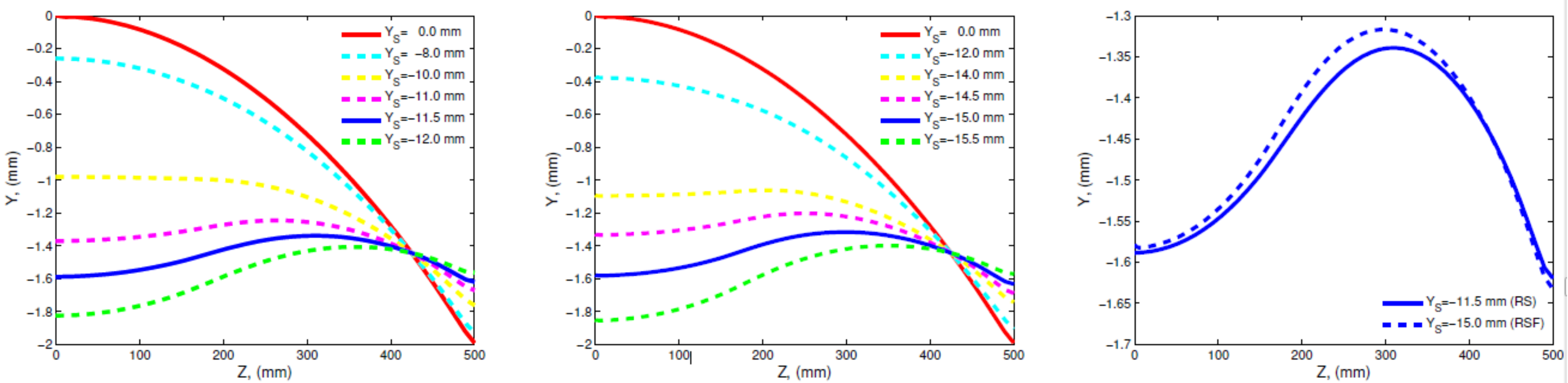

Fig. Distortion evolution along Z axis for configuration P1 and different Strokes Ys
Left) Residual Stresses (RS). Centre) Residual Stresses Free (RSF). Right) Detail: minimized distortion

Reshaping: Experiment (1/2)

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Goals
To study reshaping in a controlled environment
To test the selected material model (Chaboche)

Problem setup
AA 7010T7451
General dimensions: 200x60x20 mm
Imposed vertical stroke Ys = ±9.5 mm (x3)

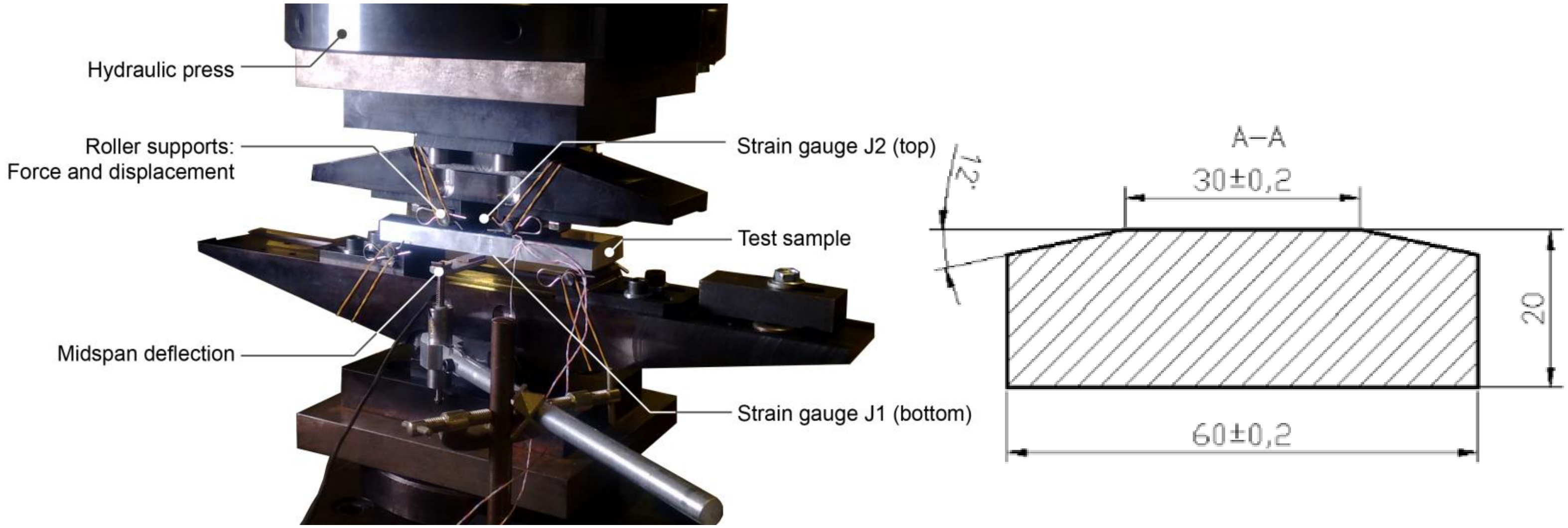

Fig. Four point bending test. Experimental setup (left), Beam ‘s cross section (right)

Reshaping: Experiment (2/2)

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Results

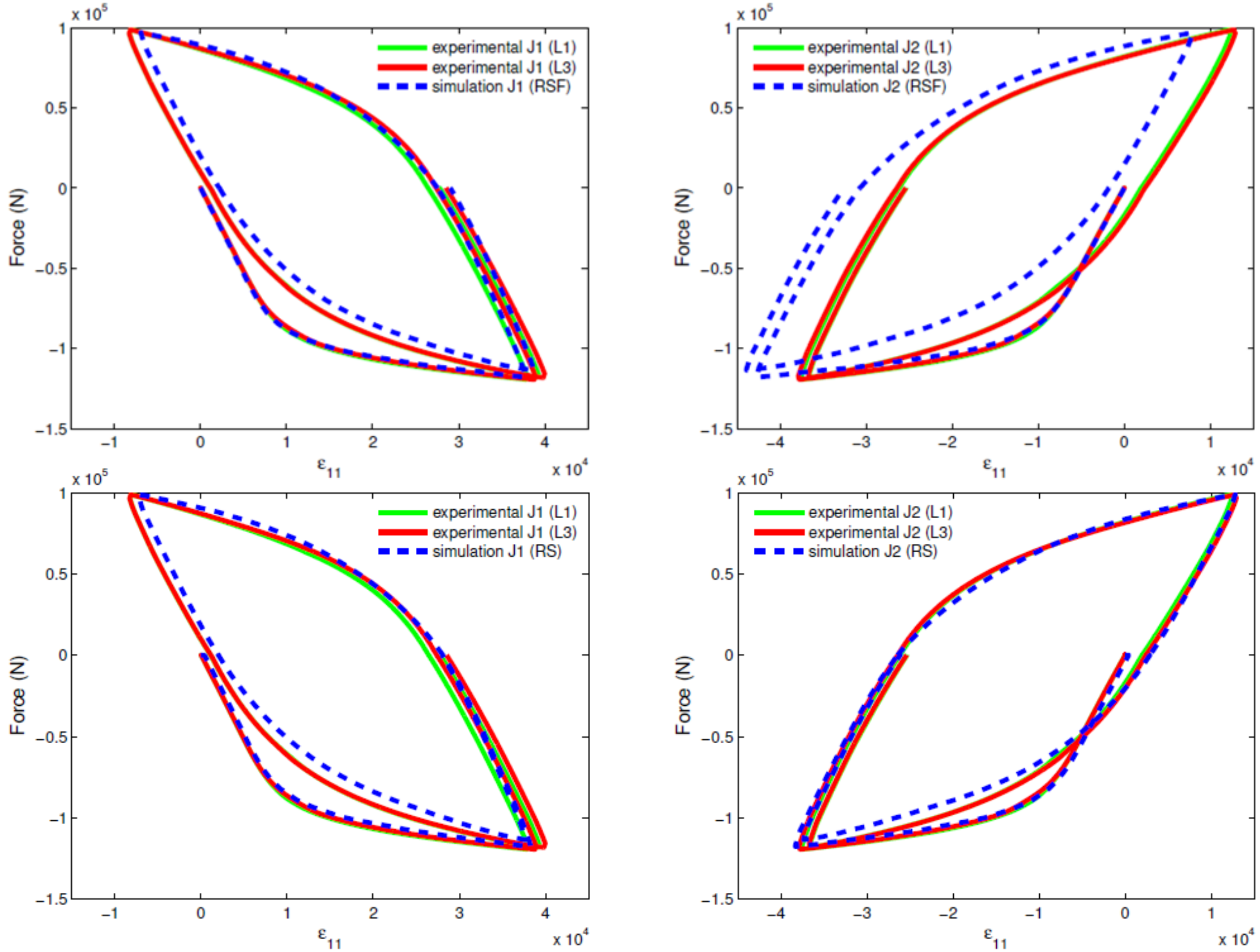

Fig. Four point bending test. Strain Gauge J1(left), Strain Gauge J2 (right). RSF (top), RS (bottom)

Reshaping: Challenges

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Reshaping simulation: Main ingredients
An efficient and adaptative algorithm
An accurate material model

Simulation error as a snow ball
Each simplification hypothesis introduces error in our results
How can I trust in my numerical results?
How to quantify the level of error?
Reshaping is done iteratively…

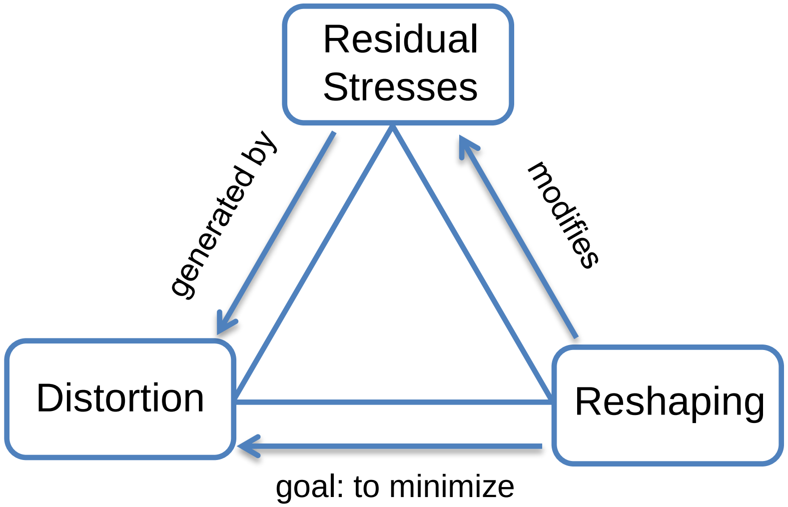

Fig. Connection between Residual Stresses, Distortion and Reshaping

Conclusions and future works

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Summary of the results
- Sequential simulation of Reshaping
- Influence of RS during reshaping
- Chaboche material model validation
- Awareness of simplification hypothesis

Ongoing and future investigations
- Do we need to simulate a complete 3D model?
- Model Order Reduction for reshaping (SSL method)

Expected outcome
- Numerical methodology to study reshaping
- Virtual demonstrator (computational vademecum)

Impact of the work from the academic and/or industrial POV
- Guided reshaping operation
- Productivity increment at workshop level
- Virtual manufacturing training environment

References

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