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Simulation of Metastable Austenitic Stainless Steels with LS-DYNA

B. Hochholdinger, ETH Zurich

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Agenda

- Metastable Austenitic Stainless Steels
- Hänsel – Model for metastable austenitic steels
- Simulation examples
- Summary and Outlook

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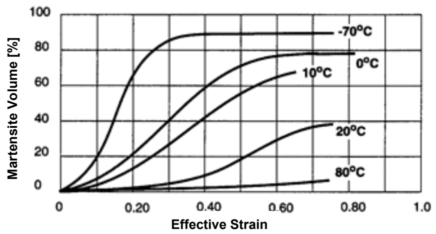
Metastable Austenitic Stainless Steels I

- Deformation based phase transformation from austenite to martensite
  - ➔ strain-induced martensite
- Formation of strain-induced martensite depends on:
  - alloy composition (high martensite volume for low Ni-content)
  - martensite volume
  - temperature



Ref.: Hänsel, ETH Zurich, (1998)

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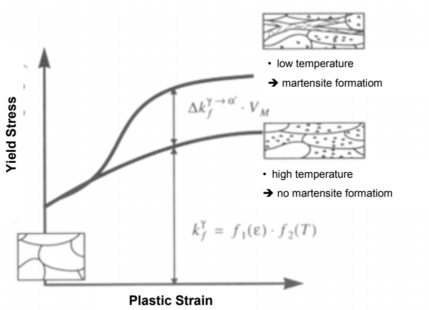
Metastable Austenitic Stainless Steels II

- Formation of martensite effects mechanical properties of material:
  - work-hardening (higher yield stress)
  - ductility/formability



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Material Model in LS-DYNA:
*MAT_TRIP (*MAT_113)

- Model as suggested by Hänsel (ETH Zurich):
  - Martensite rate as a function of martensite volume and temperature
  - Extended Hocket-Sherby hardening rule
- Non-isothermal Model
  - temperature from coupled thermo-mechanical analysis
  - adabiatic temperature calculation

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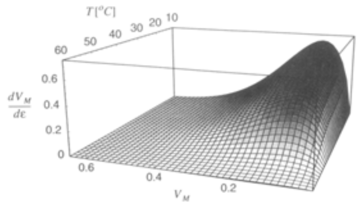
Hänsel Model:
Martensite Rate Equation

- Martensite rate as a function of martensite volume and temperature

$$\text{if } \varepsilon < \mathrm{E}_{0(\mathrm{mart})} \Rightarrow \frac{\partial V_M}{\partial \varepsilon_p} = 0$$

$$\text{else if } \varepsilon \geq \mathrm{E}_{0(\mathrm{mart})} \Rightarrow \frac{\partial V_M}{\partial \varepsilon_p} = \frac{B}{A} e^{Q/T} \left(\frac{1 - V_M}{V_M} \right)^{\frac{1+B}{B}} (V_M)^p \left[0.5 \cdot (1 - \tanh(C + D \cdot T)) \right]$$



Ref.: Hänsel, ETH Zurich, (1998)

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Hänsel Model: Hardening Rule

- Extended Hocket-Sherby function

$$\sigma_y = \left[B_{HS} - \left(B_{HS} - A_{HS}\right)e^{-m(\varepsilon_p+\varepsilon_0)^n}\right]\left(K_1 + K_2 T\right) + \Delta H_{\gamma\rightarrow\alpha'} V_M$$

increase of yield stress due to formation of martensite

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Simulation Examples

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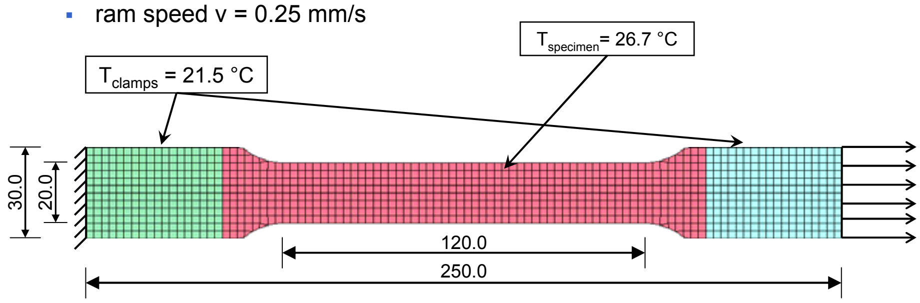
Simulation of Tension Test

- Steel grade: 1.4301
- Coupled thermo-mechanical analysis
  - 90 % of the plastic work is converted to heat
  - heat conduction, convection, initial temperatures
  - ram speed v = 0.25 mm/s



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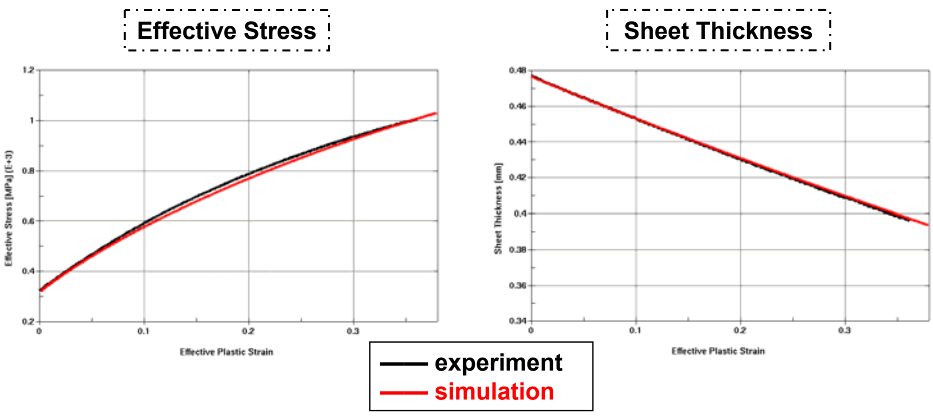
Tension Test: Results I

- Evaluation of results at center of specimen



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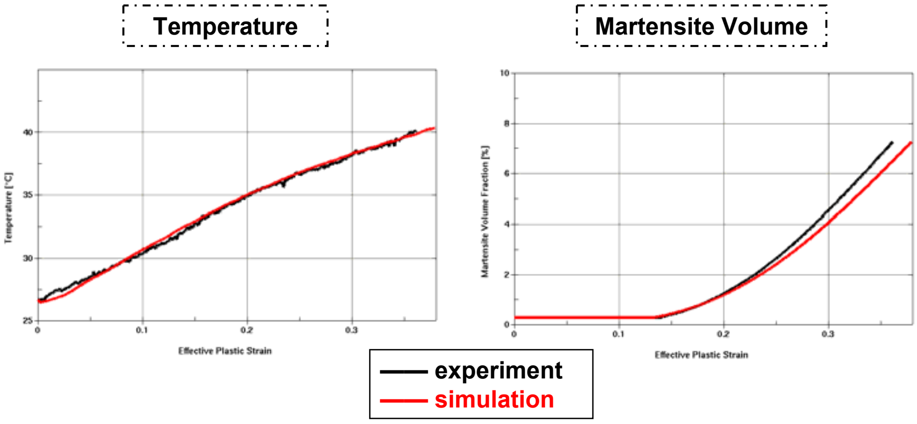
Tension Test: Results II

- Evaluation of results at center of specimen



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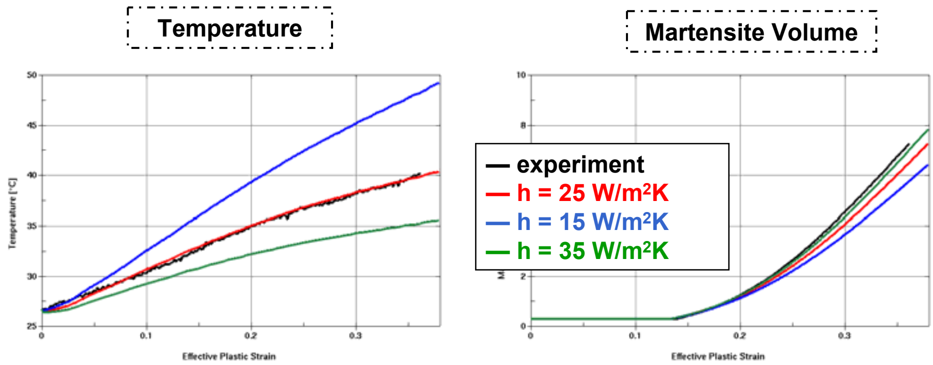
Influence of thermal boundary conditions

- Estimates for heat transfer coefficient for convection to environment:
  - natural convection in air: h ≈ 5 W/m^2K
  - forced convection in air: h ≈ 200 W/m^2K



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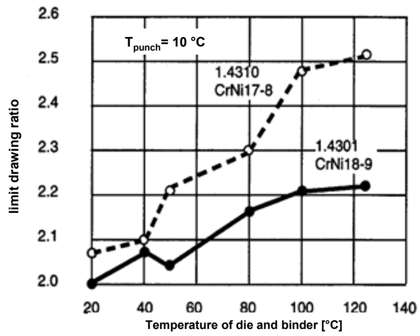
Limit Drawing Ratio for Cup Drawing

- Metastable austenitic stainless steels:
  - temperature dependent work hardening

➔ limit drawing ratio can be increased by controlling the tool temperature



T_{punch} = 10 °C
T_{die} and T_{binder} are varied

Ref.: Hänsel, ETH Zurich, (1998)

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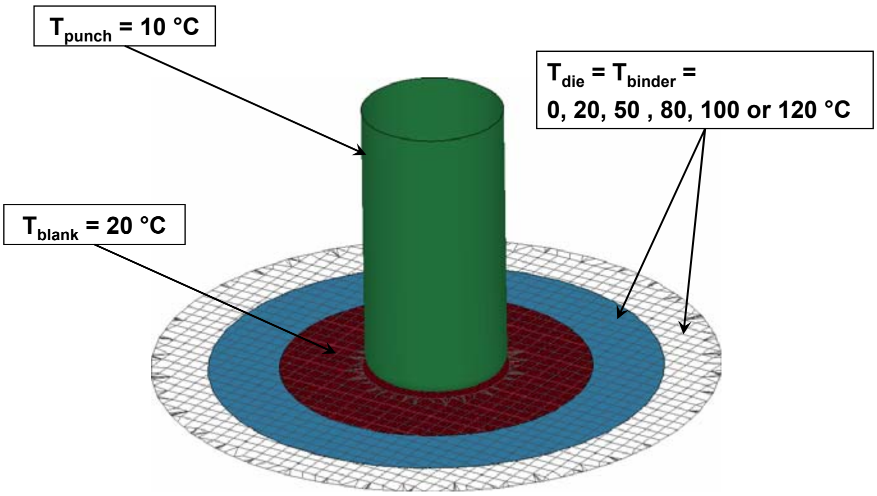
Model for Cup Drawing



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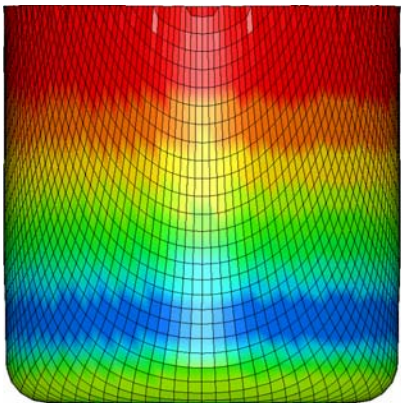
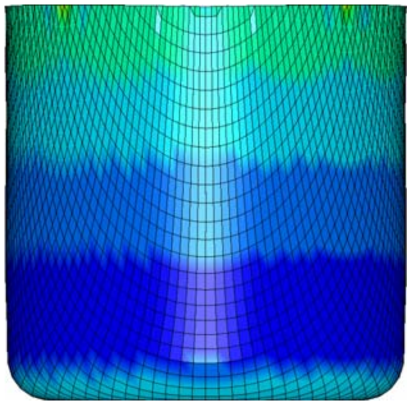
Martensite Volume for Draw Ratio 2.2

$T_{die} = T_{binder} = 20$ °C



$T_{die} = T_{binder} = 100$ °C



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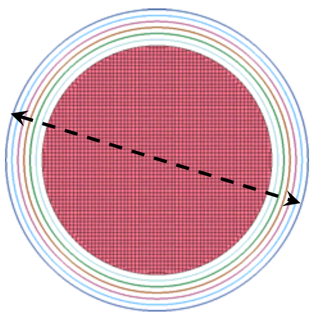
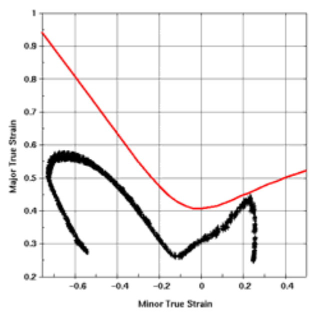
Determination of Limit Drawing Ratio

- Simple optimization procedure with LS-OPT for each chosen temperature:
  - objective function: **"maximize blank diameter"**
  - strict constraint: **"preserve FLC"**





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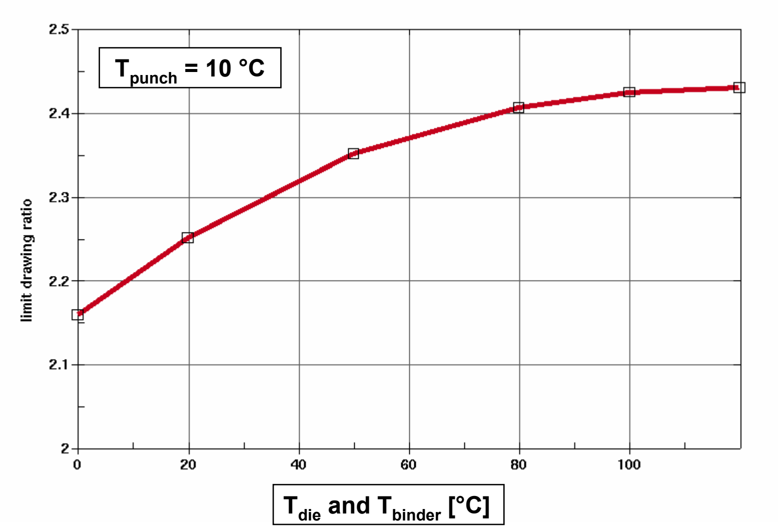
Result: Limit Drawing Ratio



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Kitchen Sink: Material 1.4301 (CrNi18 9)

Ref.: Hänsel, ETH Zurich, (1998)

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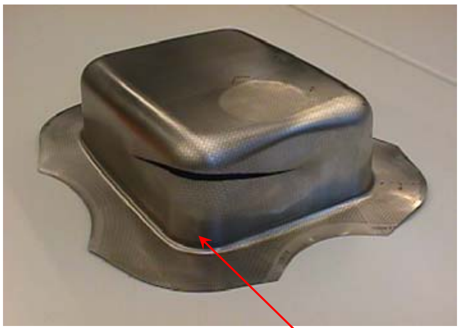
Kitchen Sink

- Temperature dependency of material properties

T_{Tools} = 20 °C



Martensite fraction: 11.5 %

T_{Tools} = 55 °C

Martensite fraction: 6.8 %

Ref.: Hänsel, ETH Zurich, (1998)

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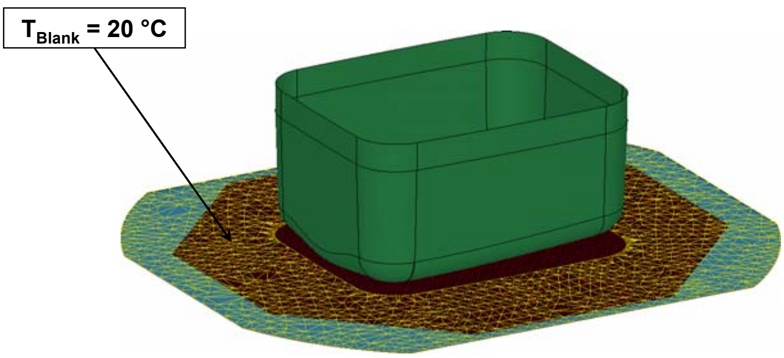
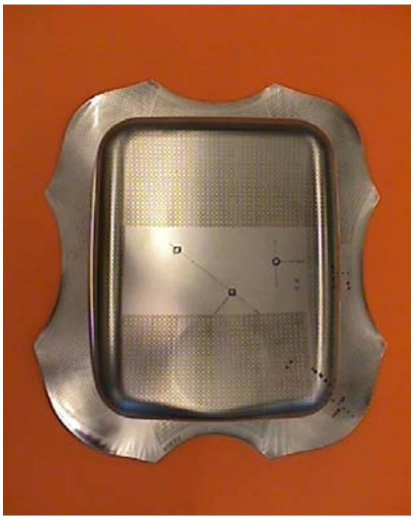
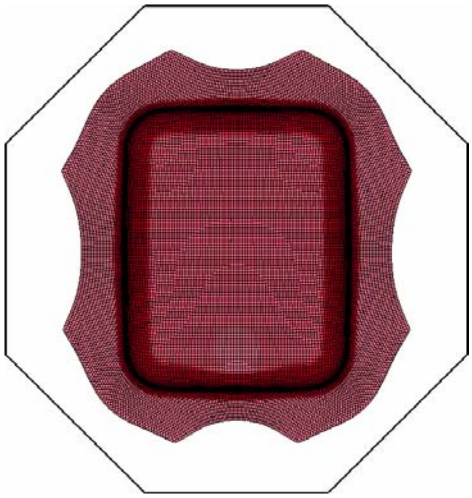
Simulation Model of Sink

- Steel grade 1.4301, Sheet thickness: 0.83 mm
- Coupled thermo-mechanical analysis …



Simulation of Kitchen Sink: Draw-in

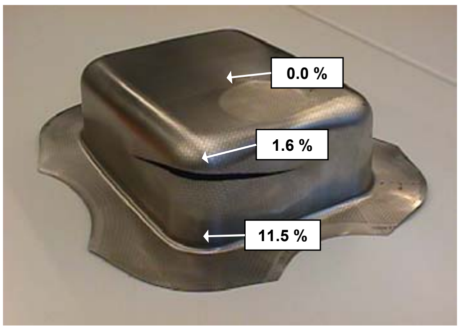


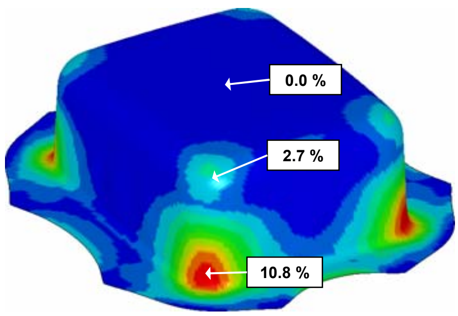


Ref.: Hänsel, ETH Zurich, (1998)

Comparison of Martensite Volume I

- T_{Tools}= 20 °C





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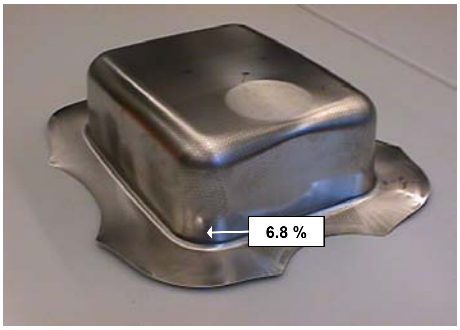
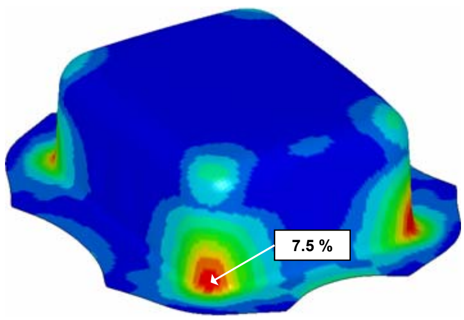
Comparison of Martensite Volume II

- T_{Tools} = 55 °C





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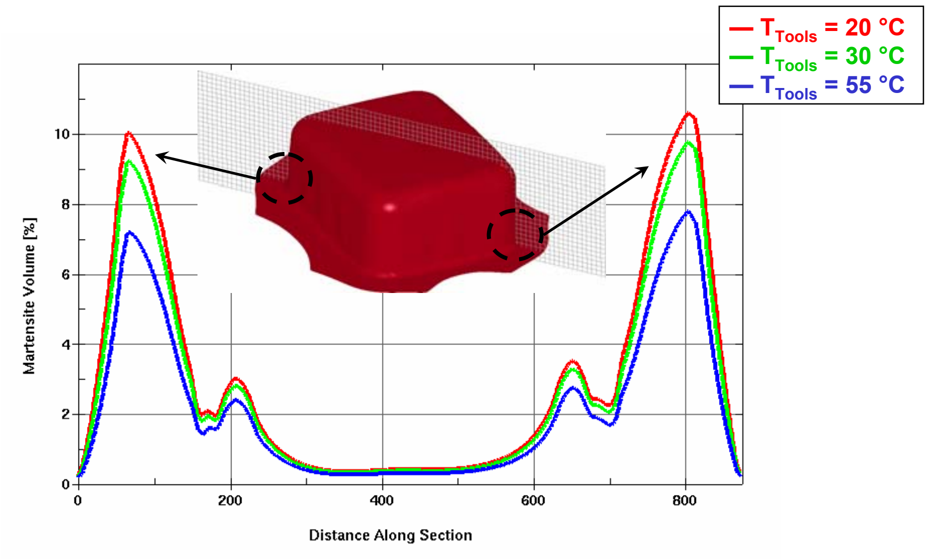
Martensite Volume



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Summary and Outlook

- Material model `*MAT_TRIP` in LS-DYNA Version 971:
  - capability to include TRIP-effect in simulation
  - in coupled thermo-mechanical analysis adequate thermal boundary conditions and thermal material parameters have to be chosen
- Current limitations:
  - isotropic Von Mises yield surface
- Further work:
  - anisotropic yield surface
  - failure prediction
  - sensitivity study regarding the thermal parameters

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Thank you for your attention

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