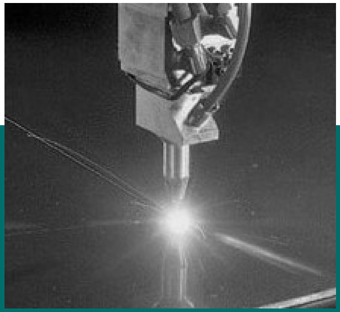
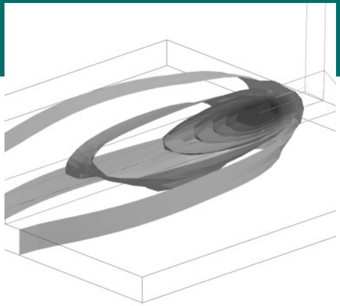
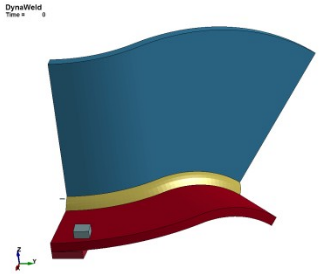




MAT_254

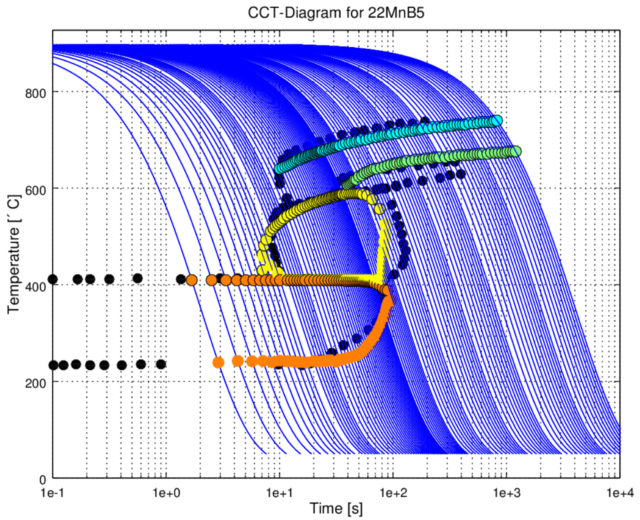


Dr.-Ing. Thomas Klöppel

DYNAmore GmbH

*MAT_UHS_STEEL/*MAT_244

- Material tailored for hot stamping / press hardening processes
  - Phase transition of austenite into ferrite, pearlite, bainite and martensite for cooling
  - Strain rate dependent thermo-elasto-plastic properties defined for individual phases
  - Transformation induced plasticity algorithm
  - Re-austenitization during heating
  - User input for microstructure computations
    is chemical composition alone



- Added:
  - Transformation induced strains
  - Welding functionality
  - Different transformation start temperatures for heating and for cooling

***MAT_244 is only valid for a narrow range of steel alloys!**

Heuristic formulas connecting chemistry with mechanics fail otherwise!

*MAT_254 / *MAT_GENERALZE_PHASE_CHANGE

- New material formulation in LS-DYNA with:
  - Up to 24 individual phases
  - List of generic phase change mechanisms (Leblond, JMAK, Koistinen-Marburger,…) for each possible phase change
  - Material incorporates all features of *MAT_244
  - Phase change parameters are given in tables and are not computed by chemical composition
- Parameter of the material might come from a material database or a microstructure calculation
- Will be suitable for a wider range of steel alloys and aluminum alloys

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 1	MID	RHO	N	E	PR	MIX	MIXR	BETA
Card 2	TASTART	TAEND	TABCTE				DTEMP	TIME
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			
Card 5	PTEPS	TRIP				GRAI		
Card 6	LCY1	LCY2	LCY3	LCY4	LCY5	LCY6	LCY7	LCY8
Card 7	LCY9	LCY10	LCY11	LCY12	LCY13	LCY14	LCY15	LCY16
Card 8	LCY17	LCY18	LCY19	LCY20	LCY21	LCY22	LCY23	LCY24

- Special welding card not needed. Liquid filler can be accounted for by an additional phase

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 1	MID	RHO	N	E	PR	MIX	MIXR	BETA

- N: Number of phases in microstructure
- E: Young’s modulus
  - LT.0: |E| is load curve ID/table ID for E vs. temperature (vs. phase)
- PR: Poissons’s ratio
  - LT.0: |E| is load curve ID/table ID for PR vs. temperature (vs. phase)
- MIX: Load curve ID for initial phase concentrations
- MIXR: LC / TAB ID for mixing rule (temperature dependent)

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 2	TASTART	TAEND	TABCTE				DTEMP	TIME

- TASTART: Reset of history variables start temperature
- TAEND: Reset of history variables end temperature
- TABCTE: coefficient of thermal expansion (CTE)
  - LT.0: |TABCTE| is load curve ID/table ID for CTE vs. temperature (vs. phase)
- DTEMP: Maximum temperature variation within a time step
  - If temperature increase exceeds DTEMP, sub time steps locally on integration point level are used
  - Important for rapid heating and cooling scenarios to resolve non-linearities

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			

- PTLAW: Table ID containing phase transformation laws
  - If law ID.GT.0: used for cooling
  - If law ID.LT.0: used for heating
  - |LAW ID|:
    - EQ.1: Koistinen-Marburger
    - EQ.2: JMAK
    - EQ.3: Kirkaldy (only cooling)
    - EQ.4: Oddy (only heating)
- PTSTR: Table ID containing start temperatures
- PTEND: Table ID containing end temperature
- PTX*i*: *i*-th scalar parameter (2D table input)
- PTTAB*i*: *i*-th temperature dependent parameter (3D table input)

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			

- Koistinen Marburger:
Koistinen Marburger:
  - Evolution equation:
Evolution equation:

$$x_b = x_a\left(1.0 - e^{-\alpha(T_{start} - T)}\right)$$

  - Parameter:
Parameter:
    - PTX1:
PTX1: α

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			

- Generalized Johnson-Mehl-Avrami-Kolmogorov (JMAK):
  - Evolution equation:

- Generalized Johnson-Mehl-Avrami-Kolmogorov (JMAK):
  - Evolution equation:

$$\frac{dx_b}{dt} = n(T)(k_{ab}x_a - k'_{ab}x_b)\left(\ln\left(\frac{k_{ab}(x_a + x_b)}{k_{ab}x_a - k'_{ab}x_b}\right)\right)^{\frac{n(T)-1.0}{n(T)}}$$

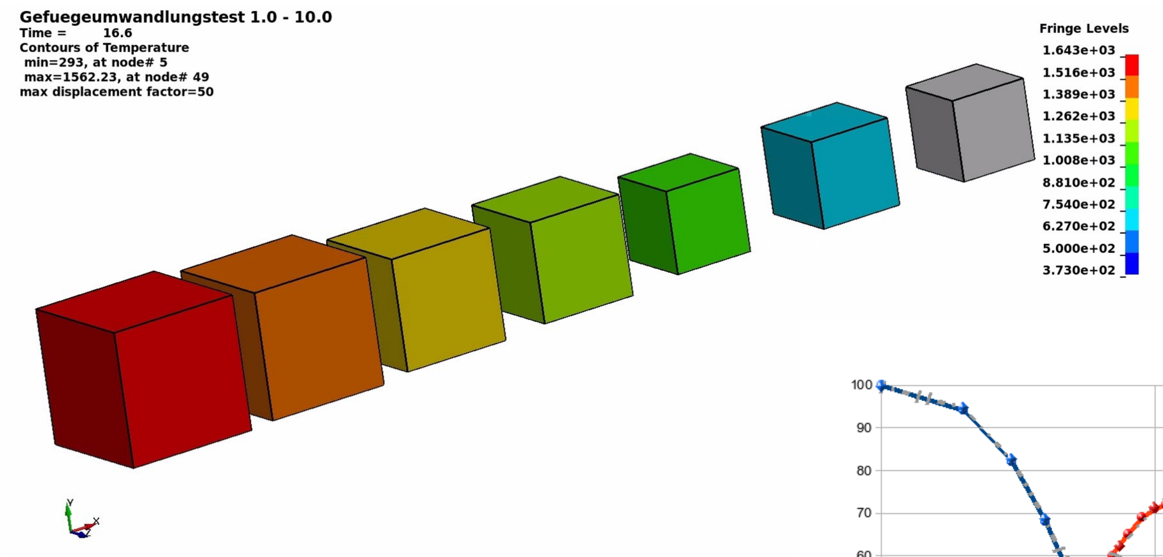
$$k_{ab} = \frac{x_{eq}(T)}{\tau(T)} f(\dot{T}), k'_{ab} = \frac{1.0 - x_{eq}(T)}{\tau(T)} f'(\dot{T})$$

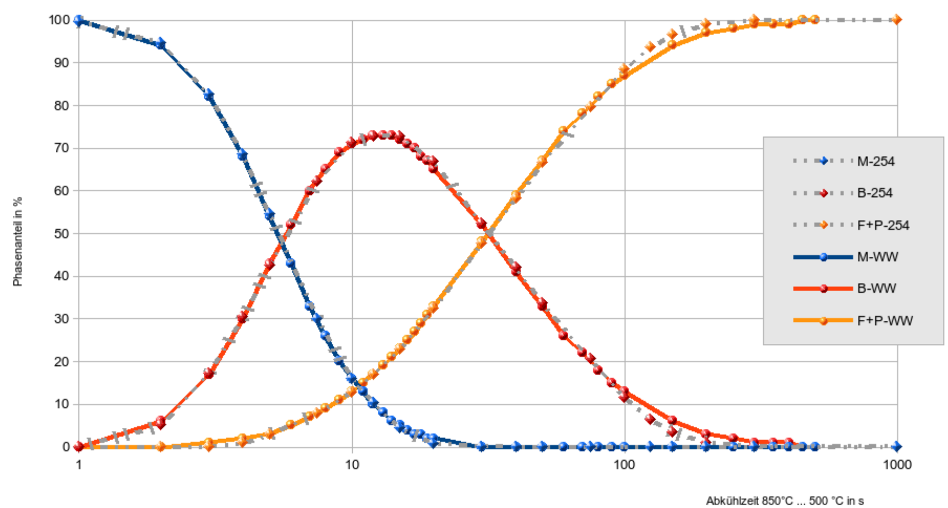
- Parameter:
  - PTTAB1:
  - PTTAB2:
  - PTTAB3:
  - PTTAB4:
  - PTTAB5:

- Parameter:
  - PTTAB1: $n(T)$
  - PTTAB2: $x_{eq}(T)$
  - PTTAB3: $\tau(T)$
  - PTTAB4: $f(\dot{T})$
  - PTTAB5: $f'(\dot{T})$

*MAT_254 with JMAK

- First example: Phase change test for steel S420





*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			

- Kirkaldy (equivalent to *MAT_244):
  - Evolution equation:

$$\frac{dX_b}{dt} = 2^{0.5(G-1)} f(C)(T_{start} - T)^{n_T} D(T) \frac{X_b^{n_1(1.0-X_b)}(1.0 - X_b)^{n_2 X_b}}{\mathrm{Y}(X_b)}, x_b = X_b x_{eq}(T)$$

  - Parameter:
    - PTX1: $f(C)$
    - PTX2: n_T
    - PTX3: n_1
    - PTX4: n_2
    - PTTAB1: $\mathrm{D}(T)$
    - PTTAB2: $\mathrm{Y}(X_b)$
    - PTTAB3: $x_{eq}(T)$

Kirkaldy (equivalent to *MAT_244):
Evolution equation:
Parameter:
PTX1:
PTX2:
PTX3:
PTX4:
PTTAB1:
PTTAB2:
PTTAB3:

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 3	PTLAW	PTSTR	PTEND	PTX1	PTX2	PTX3	PTX4	PTX5
Card 4	PTTAB1	PTTAB2	PTTAB3	PTTAB4	PTTAB5			

- Oddy (equivalent to *MAT_244):
  - Evolution equation:
  - Parameter:
    - PTX1:
    - PTX2:
    - PTX3:

- Generalized Johnson-Mehl-Avrami-Kolmogorov (JMAK):
  - Evolution equation:

$$\frac{dx_b}{dt} = n(T)(k_{ab}x_a - k'_{ab}x_b)\left(\ln\left(\frac{k_{ab}(x_a + x_b)}{k_{ab}x_a - k'_{ab}x_b}\right)\right)^{\frac{n(T)-1.0}{n(T)}}$$

$$k_{ab} = \frac{x_{eq}(T)}{\tau(T)} f(\dot{T}), k'_{ab} = \frac{1.0 - x_{eq}(T)}{\tau(T)} f'(\dot{T})$$

  - Parameter:
    - PTTAB1: $n(T)$
    - PTTAB2: $x_{eq}(T)$
    - PTTAB3: $\tau(T)$
    - PTTAB4: $f(\dot{T})$
    - PTTAB5: $f'(\dot{T})$

*MAT_254 / *MAT_GENERALIZED_PHASE_CHANGE

	1	2	3	4	5	6	7	8
Card 5	PTEPS	TRIP				GRAI		
Card 6	LCY1	LCY2	LCY3	LCY4	LCY5	LCY6	LCY7	LCY8
Card 7	LCY9	LCY10	LCY11	LCY12	LCY13	LCY14	LCY15	LCY16
Card 8	LCY17	LCY18	LCY19	LCY20	LCY21	LCY22	LCY23	LCY24

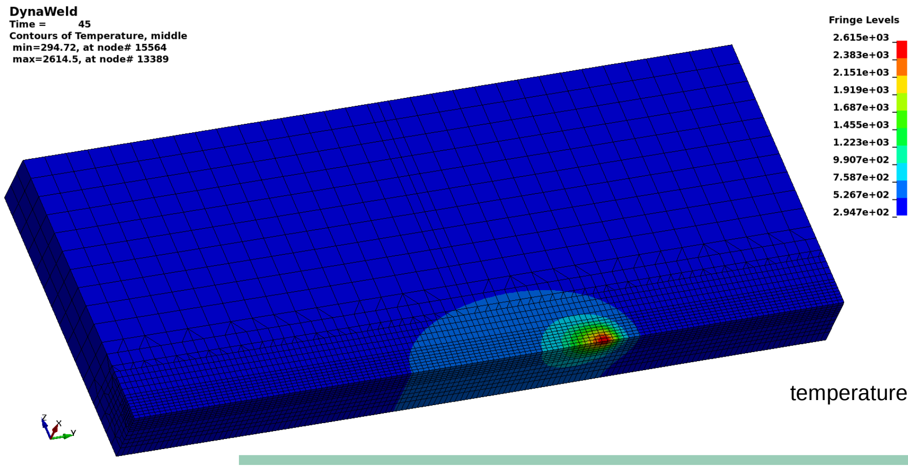
- PTEPS: Table ID for transformation induced strains
- TRIP: Flag for transformation induced plasticity (active for TRIP.gt.0)
- GRAIN: Initial grain size

- LCY*xy:* Load curve or table ID for yield stress vs. equivalent plastic strain

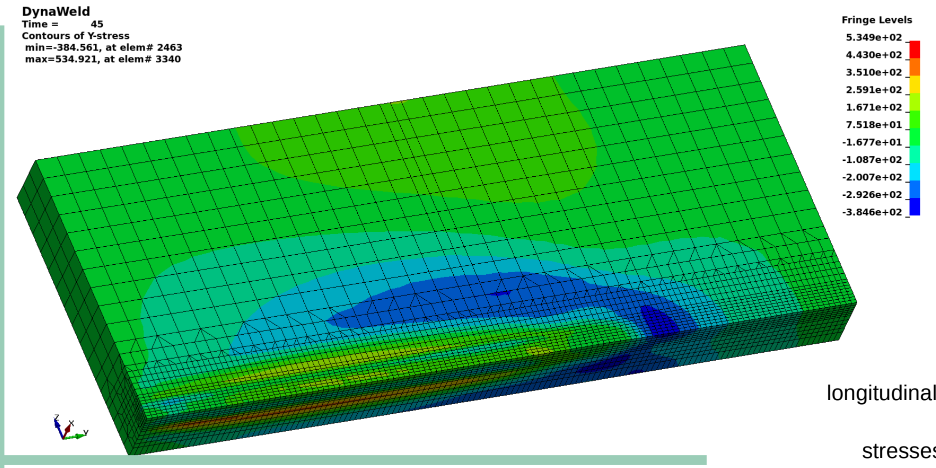
  (vs. strain rate vs. temperature)

Residual stresses

- Nitschke-Pagel test

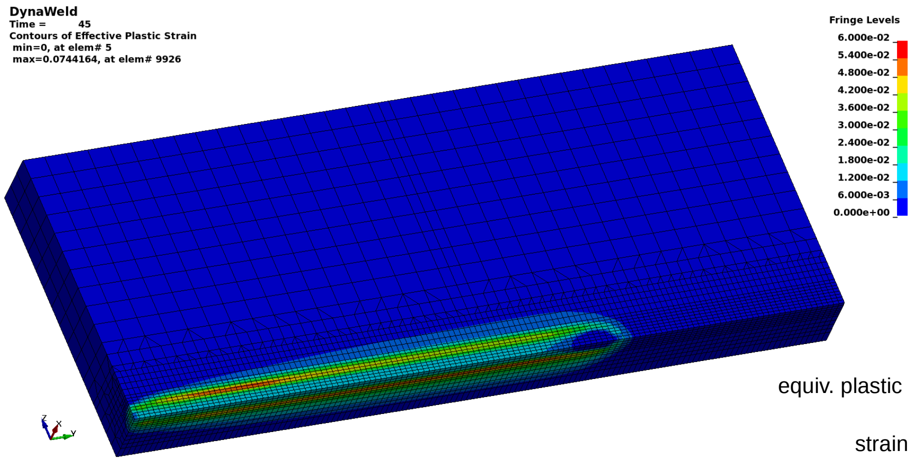


temperature



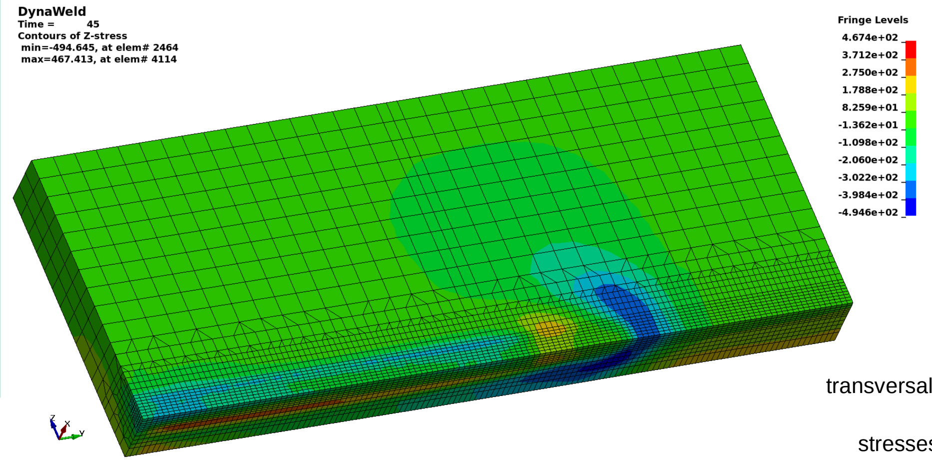
longitudinal

stresses



equiv. plastic

strain

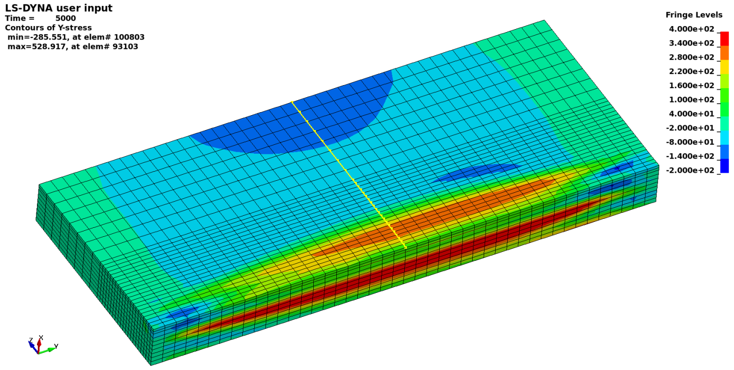


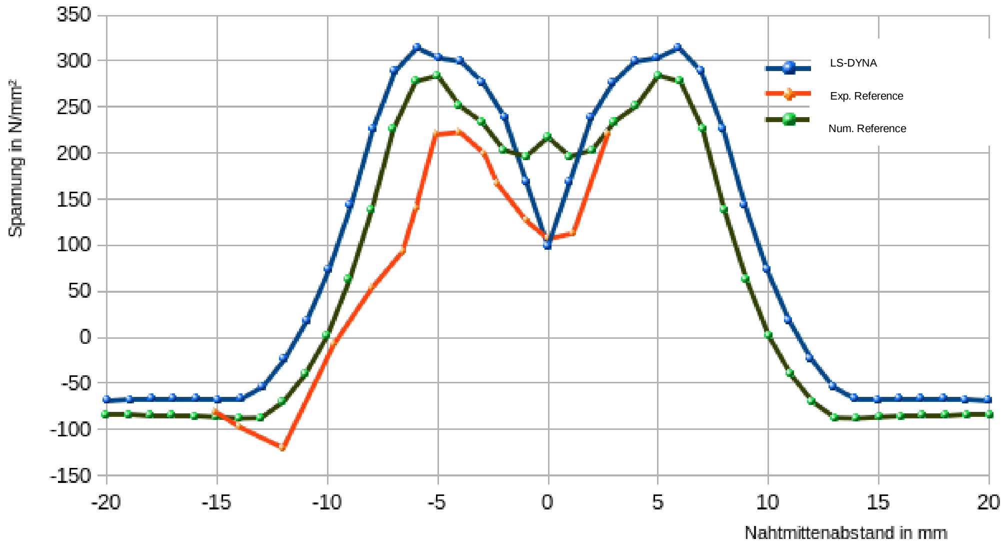
transversal

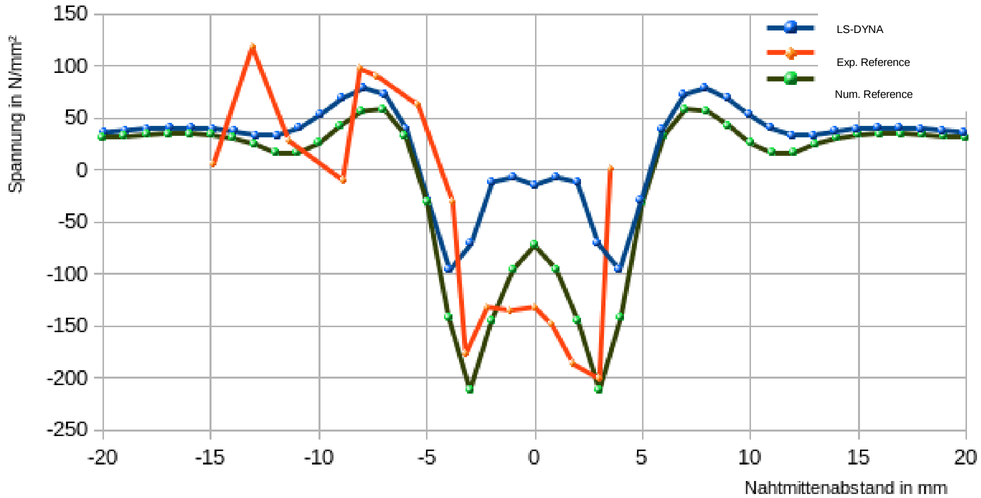
stresses

Residual stresses

- Nitschke-Pagel test







Thank you!