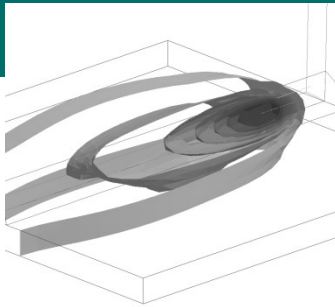
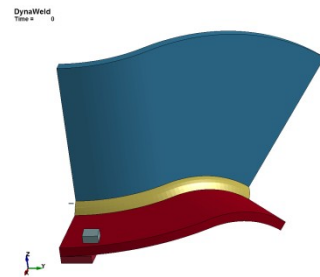


MAT_254



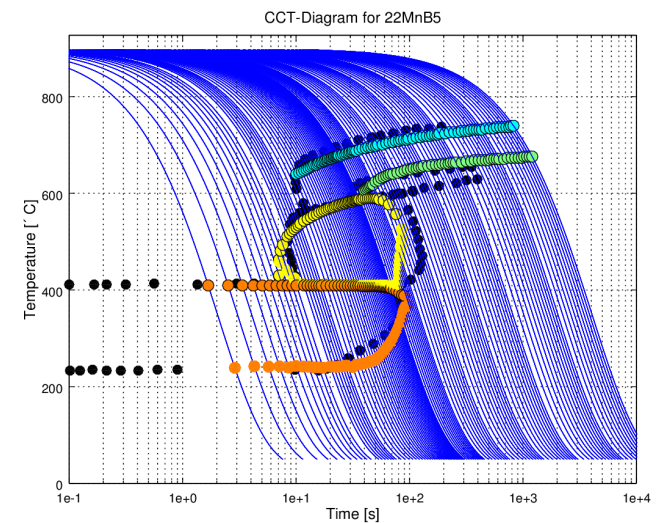
Dr.-Ing. Thomas Klöppel

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_GENERALIZE_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 | | | |

Kristin Marburger:

Evolution equation:

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

Parameter:

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:

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

Parameter:

PTTAB1:

PTTAB2:

PTTAB3:

PTTAB4:

PTTAB1: $n(T)$

PTTAB2: $x_{eq}(T)$

PTTAB3: $\tau(T)$

PTTAB4: $f(\dot{T})$

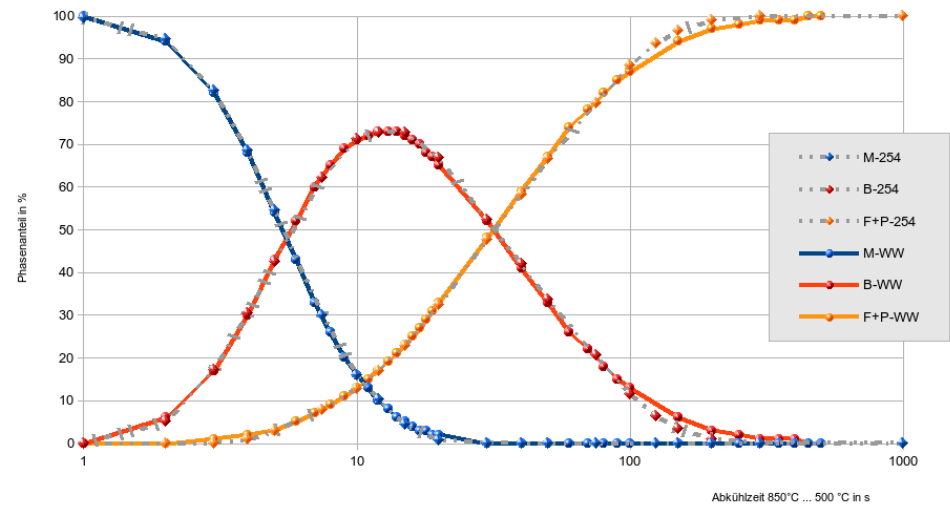
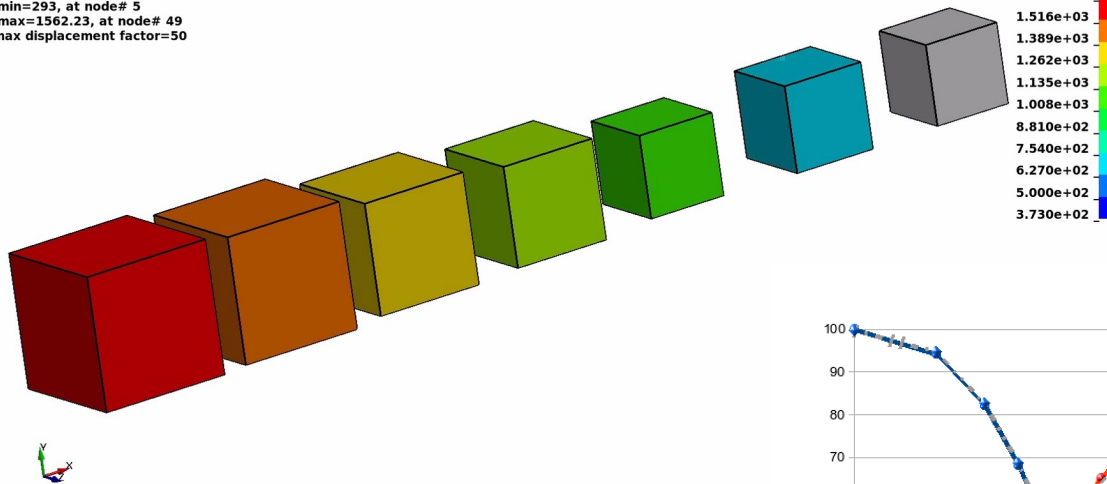
PTTAB5: $f'(\dot{T})$

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

*MAT_254 with JMAK

First example: Phase change test for steel S420

Gefügeumwandlungstest 1.0 - 10.0
Time = 16.6
Contours of Temperature
min=293, at node# 5
max=1562.23, at node# 49
max displacement factor=50



*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:

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

Parameter:

PTX1:

PTX2:

PTX3:

PTX4:

PTX5:

PTTAB1:

PTTAB2:

PTTAB3:

PTTAB4:

PTTAB5:

PTTAB6:

PTTAB7:

PTTAB8:

PTTAB9:

PTTAB10:

PTTAB11:

PTTAB12:

PTTAB13:

PTTAB14:

PTTAB15:

PTTAB16:

PTTAB17:

PTTAB18:

PTTAB19:

PTTAB20:

PTTAB21:

PTTAB22:

PTTAB23:

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PTTAB260:

PTTAB261:

PTTAB262:

PTTAB263:

PTTAB264:

PTTAB265:

PTTAB266:

PTTAB267:

PT

*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:

Parameter:

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

PTX1:

PTX2:

PTX3:

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

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
- LCYxy:

Load curve or table ID for yield stress vs. equivalent plastic strain
(vs. strain rate vs. temperature)

Residual stresses

Nitschke-Pagel test

DynaWeld
Time = 45
Contours of Temperature, middle
min=294.72, at node# 15564
max=2614.5, at node# 13389

Fringe Levels
2.615e+03
2.383e+03
2.151e+03
1.919e+03
1.687e+03
1.455e+03
1.223e+03
9.907e+02
7.587e+02
5.267e+02
2.947e+02

temperature

DynaWeld
Time = 45
Contours of Y-stress
min=-384.561, at elem# 2463
max=534.921, at elem# 3340

Fringe Levels
5.349e+02
4.430e+02
3.510e+02
2.591e+02
1.671e+02
7.518e+01
-1.677e+01
-1.087e+02
-2.007e+02
-2.926e+02
-3.846e+02

longitudinal
stresses

DynaWeld
Time = 45
Contours of Effective Plastic Strain
min=0, at elem# 5
max=0.0744164, at elem# 9926

Fringe Levels
6.000e-02
5.400e-02
4.800e-02
4.200e-02
3.600e-02
3.000e-02
2.400e-02
1.800e-02
1.200e-02
6.000e-03
0.000e+00

equiv. plastic
strain

DynaWeld
Time = 45
Contours of Z-stress
min=-494.645, at elem# 2464
max=467.413, at elem# 4114

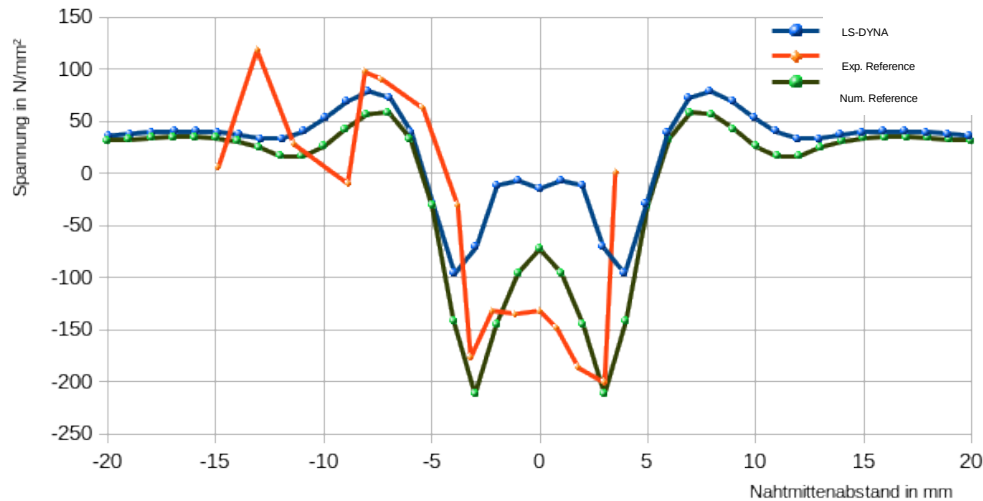
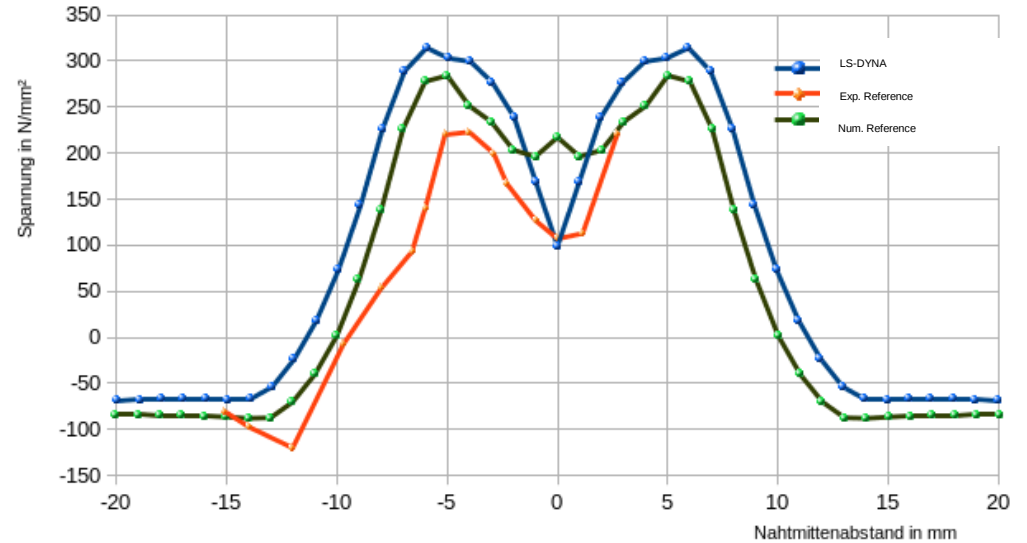
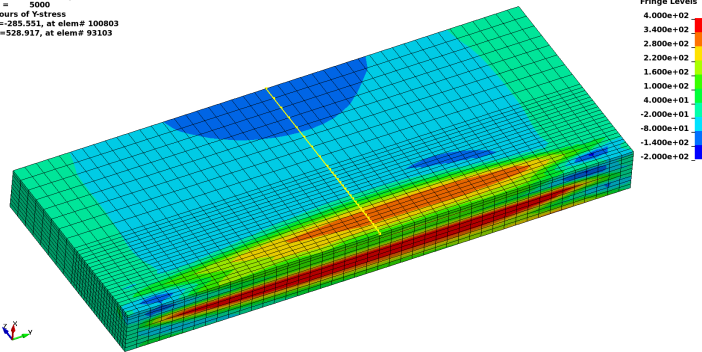
Fringe Levels
4.674e+02
3.712e+02
2.750e+02
1.788e+02
8.259e+01
-1.362e+01
-1.098e+02
-2.060e+02
-3.022e+02
-3.984e+02
-4.946e+02

transversal
stresses

Residual stresses

Nitschke-Pagel test

LS-DYNA user input
Time = 5000
Contours of Ystress
min=-285.531, at elem# 100803
max=528.917, at elem# 93103



Thank you!

