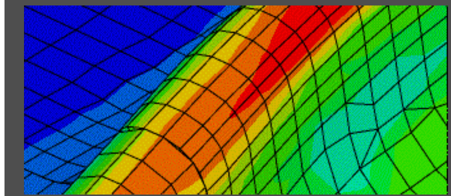


Practical Guidelines for Hot Stamping Simulations with LS-DYNA

David Lorenz
DYNAmore GmbH

Outline

1. Important process steps in hot stamping

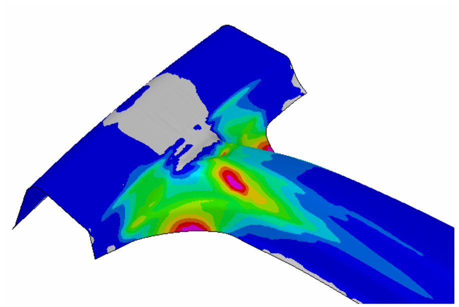
2. Transfer and gravity simulation in hot stamping

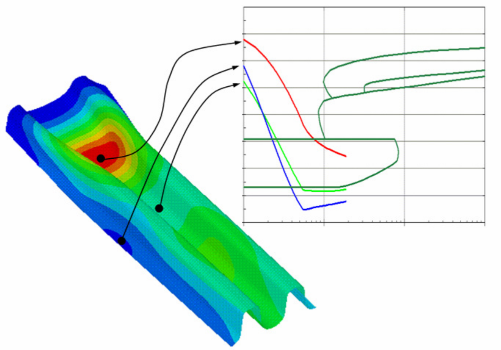
3. How to model proper material behavior

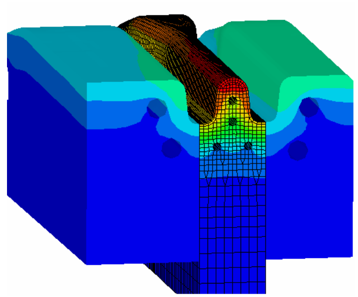
4. Thermal coupling effects

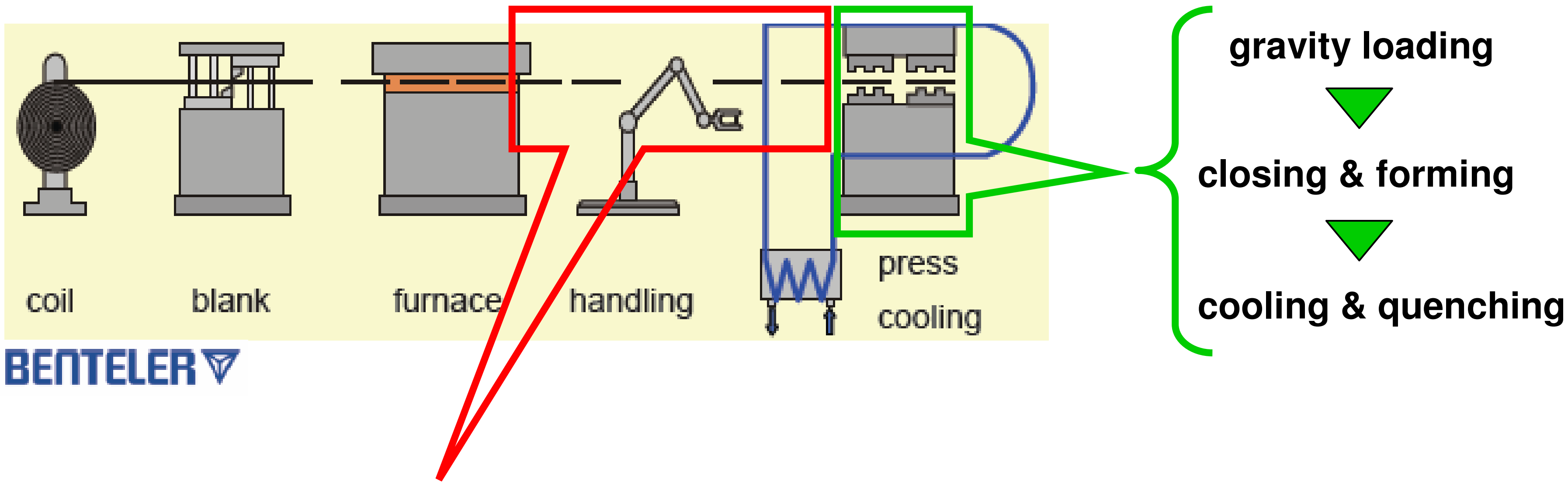
5. Notes on thermal contact

6. Solution methods for cooling simulations

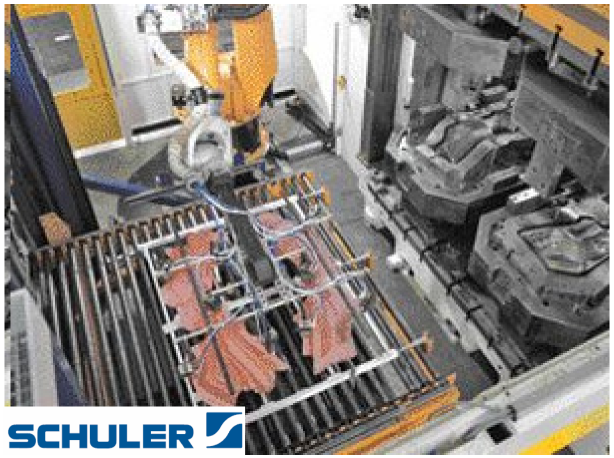




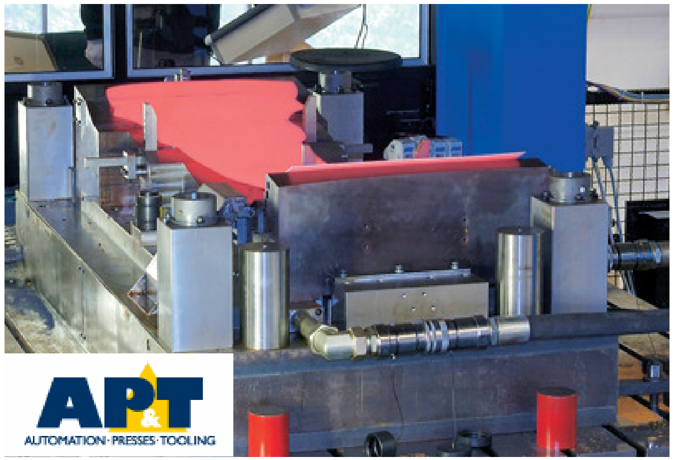




Transfer
of the hot blank to the die



gravity loading
of the hot blank on the die



DYNA MORE

During transfer from furnace to the press blank temperature drops due to radiation and convection

We can run this step thermal-mechanical coupled to account for the shrinkage of the blank due to thermal strains

```
*CONTROL_SOLUTION
$      SOLN
          2            <- Coupled solution

*CONTROL_IMPLICIT_GENERAL
$    IMFLAG        DT0
          1        0.1
```

implicit solver (IMFLAG)

choose reasonable time step (DT0)

```
*CONTROL_IMPLICIT_INERTIA_RELIEF
$    IRFLAG     THRESH
          1       0.01
```

Inertia relief (IRFLAG)

Threshold frequency (THRESH)

```
*INTERFACE_SPRINGBACK_LSDYNA
```

*CONTROL_IMPLICIT_INERTIA_RELIEF

- static solution without applying SPCs
- advantageous in unconstrained springback calculation
- eliminates all rigis body modes from the stiffness matrix
- All eigenfrequencies below the threshold frequency are treated as rigid body modes and are eliminated
- DYNA runs an eigenvalue analysis prior to the static solution

Why not using SPCs applied to single nodes of the blank ?

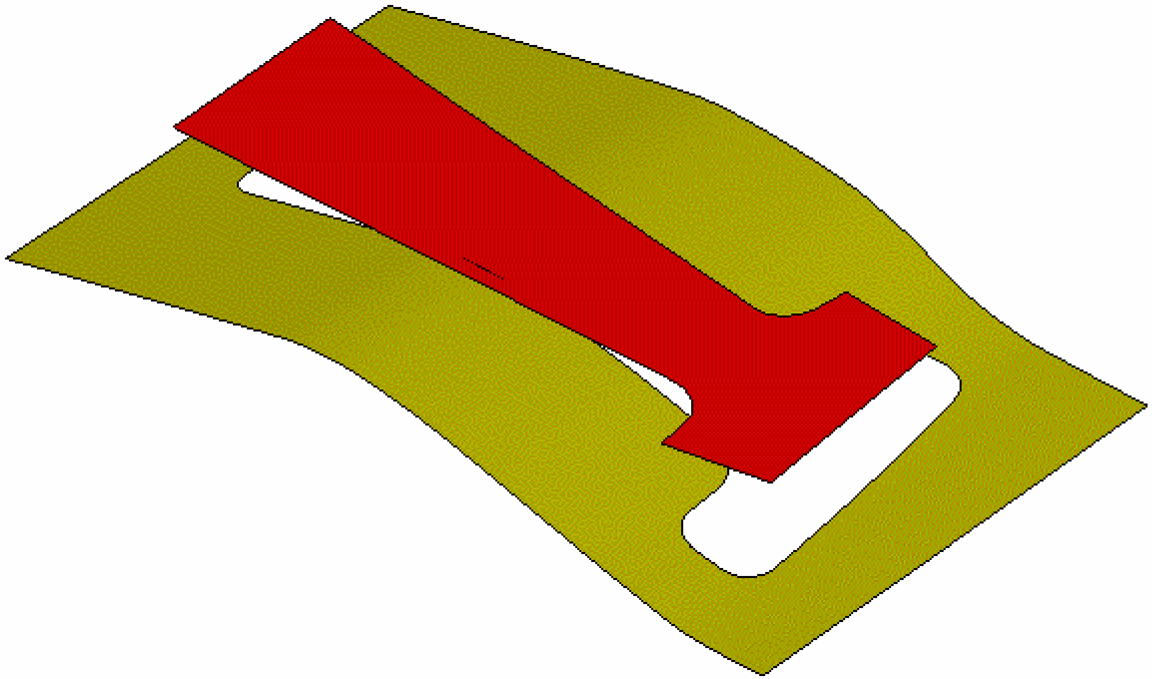
- all SPCs are written into the dynain file
- these SPCs become redundant in following gravity and forming simulation
- if you do not notice that SPCs are in the dynain file you may run into convergence trouble in the gravity step

Gravity Step in Hot Stamping Simulation

gravity deformation appears immediately

blank typically remains 1 … 3 s in ^thid position till upper die moved down

run in a few coupled steps to account for temperature loss in contact



Gravity Step in Hot Stamping Simulation

gravity deformation appears immediately

blank remains typically 1 … 3 s in till upper die moved down

run in a few coupled steps to account for temperature loss in contact

```
*CONTROL_SOLUTION
$      SOLN
          2

*CONTROL_IMPLICIT_GENERAL
$    IMFLAG       DT0
          1      0.01

*CONTROL_IMPLICIT_FORMING
$      TYPE
          1

*CONTROL_IMPLICIT_AUTO
$     IAUTO                           DTMIN     DTMAX
          1                            0.01       0.5

*CONTROL_THERMAL_TIMESTEP
$      TS    TIP     ITS   DTMIN     DTMAX     DTEMP
        1      1    0.01    0.01       0.5       10.
```

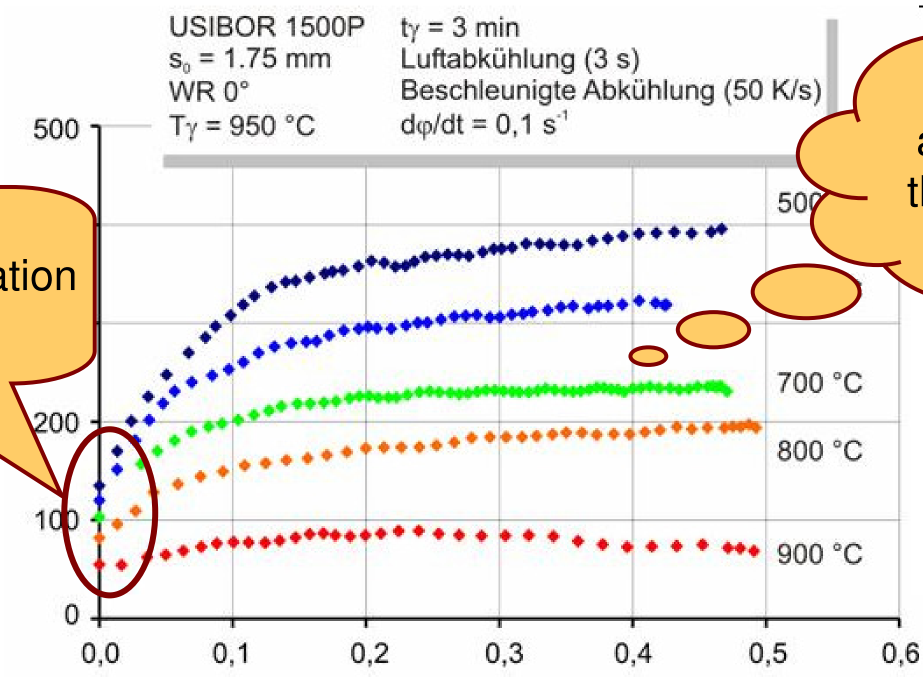
enhanced static solution (*CONTROL_IMPLICIT_FORMING TYPE 1)

automatic time stepping both mechanics & thermal (*CONTROL_IMPLICIT_AUTO, *CONTROL_THERMAL_TIMESTEP)

Why is the gravity simulation not in agreement with real process ?

- the elastic modulus of hot steel is still higher than cold aluminum
- but the yield point at high temperatures is at very low stress level

Do we accurately capture this effect in our material input ?

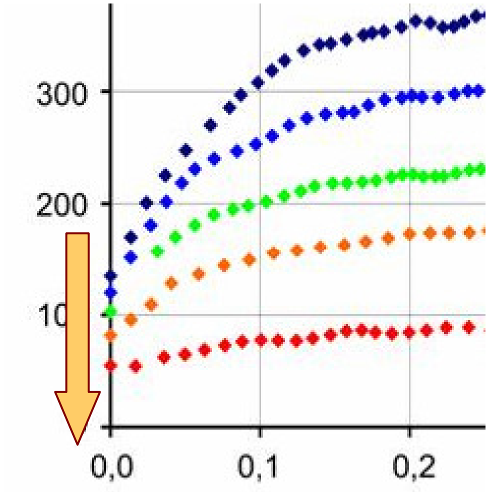


coarse resolution
yield point determination
not very accurate

these experiments
aimed to meassure
the yield curve up to
high plastic strains

Source: LFT University of Erlangen

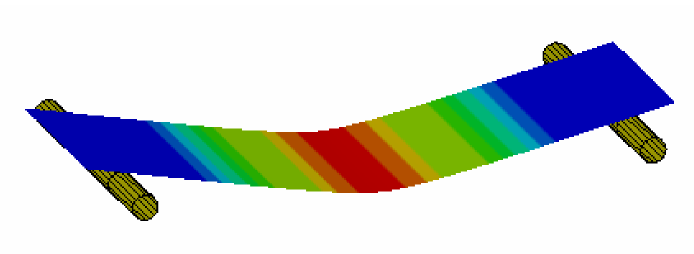
Solving this shortcoming in material input



- lower the yield point for the relevant temperatures
- bring your simulation into better agreement with your observations and experiences in real process

… or …

- make a simple experiment
- validate your material input in agreement to experiment



How to get the Cowper Symonds Parameters from given yield curves ?

$$\sigma = \sigma_0 \left[1 + \left(\frac{\dot{\varepsilon}}{C} \right)^{\frac{1}{p}} \right] \quad \Rightarrow \quad \frac{\sigma - \sigma_0}{\sigma_0} = \left(\frac{\dot{\varepsilon}}{C} \right)^{\frac{1}{p}} = \dot{\varepsilon}^{\frac{1}{p}} \cdot C^{\frac{-1}{p}}$$

logarithmizing gives an easy to solve linear equation

$$\ln \left[\frac{\sigma - \sigma_0}{\sigma_0} \right] = \frac{1}{p} \ln \dot{\varepsilon} - \frac{1}{p} \ln C$$

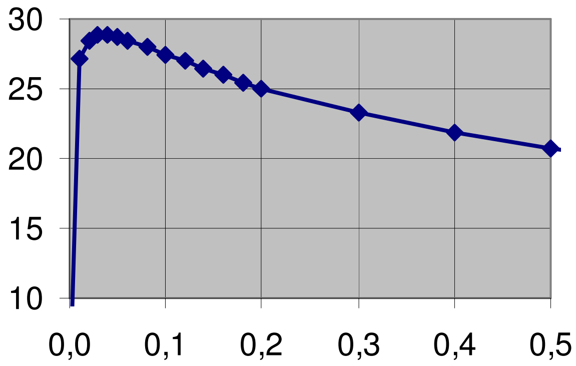
calculate ***C*** and ***p*** from slope ***m*** and intercept ***b***

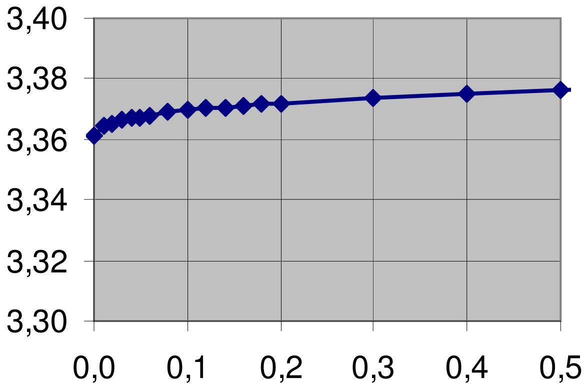
$$p = \frac{1}{m} \qquad C = e^{-b \cdot p}$$

for several plastic strains of each curve

How to get the Cowper Symonds Parameters from given yield curves ?

- calculate C and p at different plastic strains (0.1, 0.2, 0.3, …)
- we need equally spaced yield curves at different strain rates
- curve fit of each yield curve (Swift, Gosh, Hocket-Sherby etc.) necessary
- We end up with ***C*** and ***p*** as functions of ε_{pl}



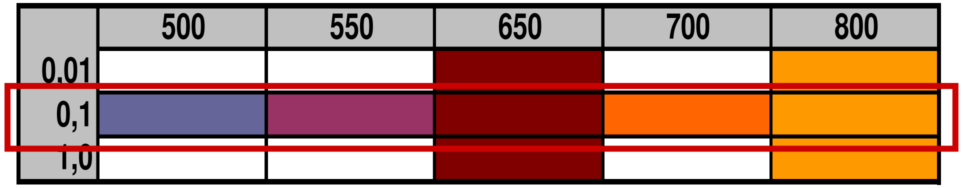


- Choose one value for ***C*** and one for ***p***
- Rate effects are important in the onset of local necking
- Choose ***C*** and ***p*** for the higher plastic strains (>0.2)

for each temperature

What if we havenot enough data (Numisheet Benchmark) ?

yield cuves provided by Numisheet BM03

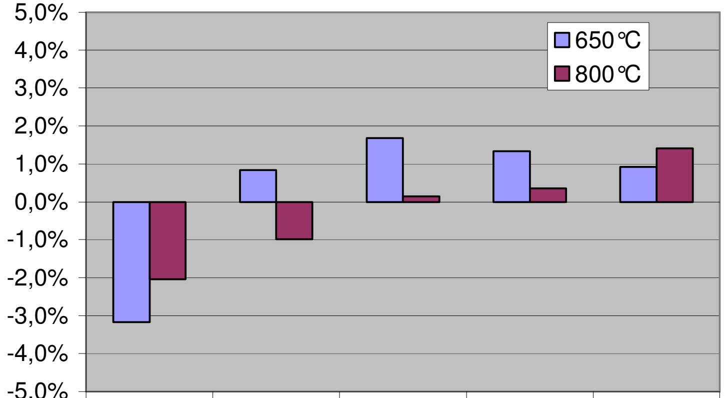


base line for table definition in MAT_106

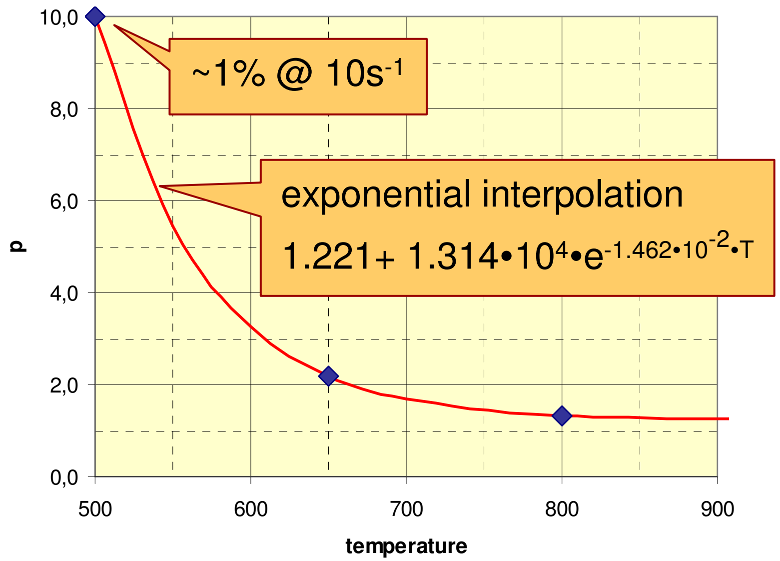
set ***C*** to a constant number ⇒ C = 10

Find ***p*** to match curves for $1.0s^{-1}$

$$\sigma = \sigma_0 \left[1 + \left(\frac{\dot{\varepsilon}}{C} \right)^{\frac{1}{p}} \right]$$

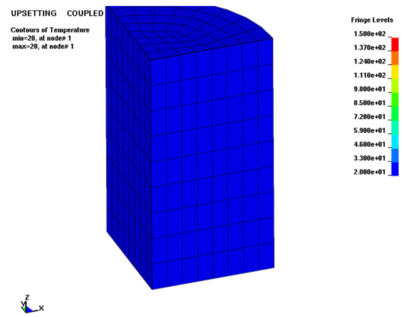


	0,05	0,1	0,15	0,2	0,25
650°C	-3,2%	0,8%	1,7%	1,3%	0,9%
800°C	-2,0%	-1,0%	0,1%	0,4%	1,4%



Do we need to account for plastic work to heat conversion ?

$$w_{pl} = \rho c_p \Delta T = \eta \int_{\varepsilon_{eq}} \sigma_{eq} d\varepsilon_{eq}$$



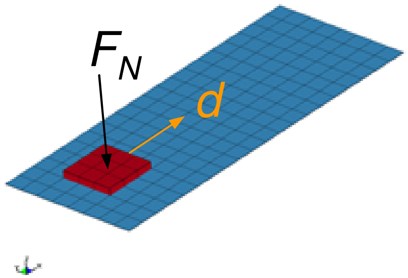
- can cause trouble if strain localization starts
- localization results in high local strain rates
- Cowper-Symonds scales up stress and thus plastic work
- high local temperature rates
- thermal solver reduces time step
- blank temperature can climb above initial value

⇨ **we won‘t loose accuracy if we neglect this effect**

⇨ **simulation is more robust without work to heat conversion**

Is it necessary to include friction heat ?

- friction coefficient is very high (0.3 …0.4)
- seems reasonable to include it



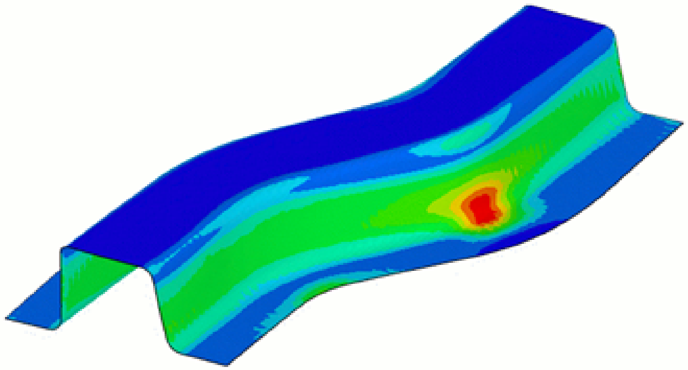
… but …

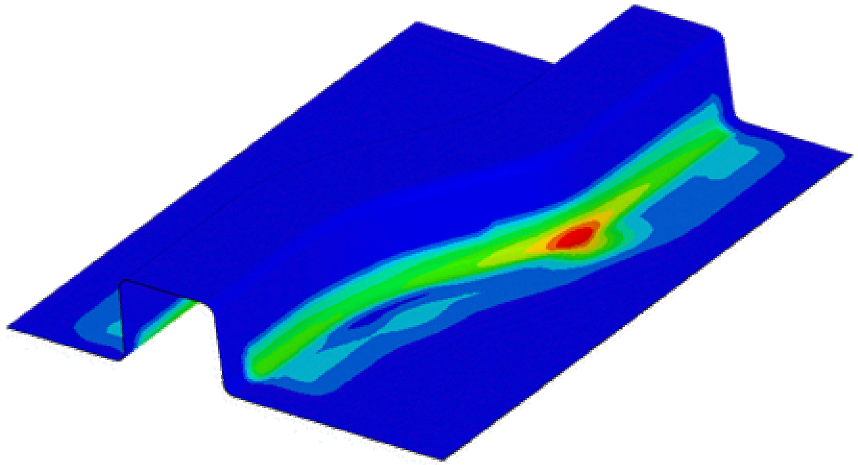
- very high local contact forces due to mass and speed scaling
- simple coulomb law predicts high friction energy
- can cause local temperature peaks in contact surface
- temperature fringes do not look reasonable

⇨ **in real life friction force is limited by blank yield stress**

⇨ **more reliable without friction energy conversion**

Application of coupling effects in cold stamping of high strength steel



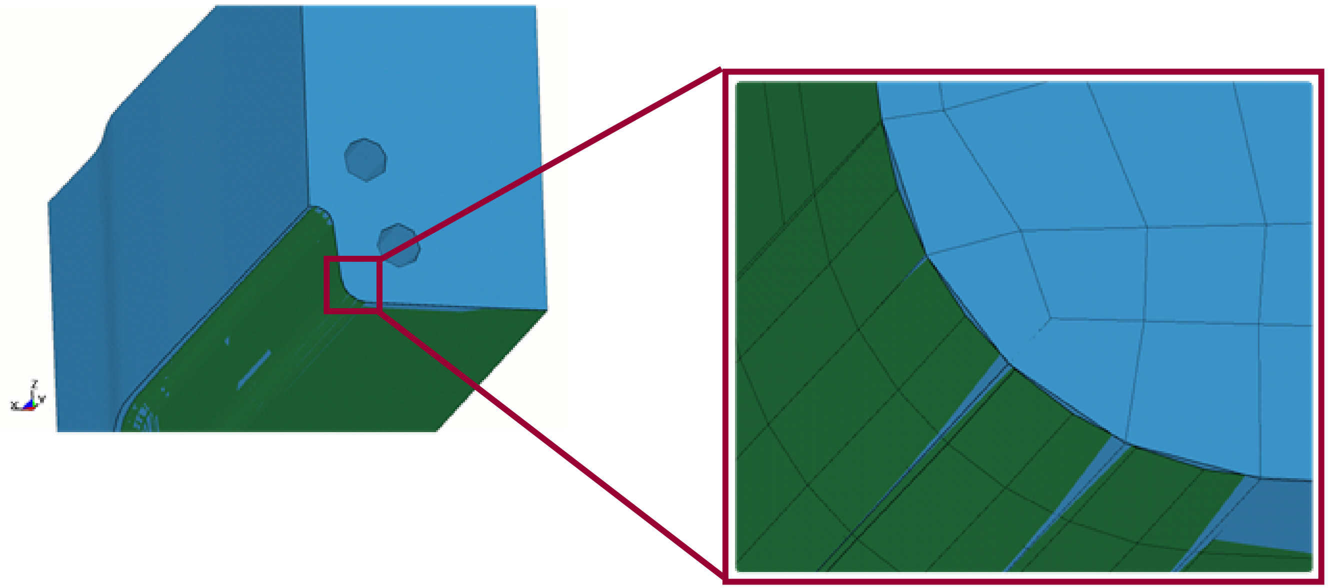


work to heat in blank

friction to heat in die

Use of thermal contact to enhance our modelling skills

- Die Surface Geometry accurately modeled with Shell Elements
- Die Volume Geometry modeled with Volume Elements **Alignment of meshes ?**
- Shell and Volume Mesh **coupled with contact definition**



⇨ independent meshing of surface and volume

⇨ Penetrations between Volume Elements and Blank Shells are ignored in the mechanical contacts

- **heat transfer from** blank to die surface shell by **thermal contact**
- **heat dissipation into** the dies by thermal contact between shell and volume mesh

Use of thermal contact to enhance our modelling skills

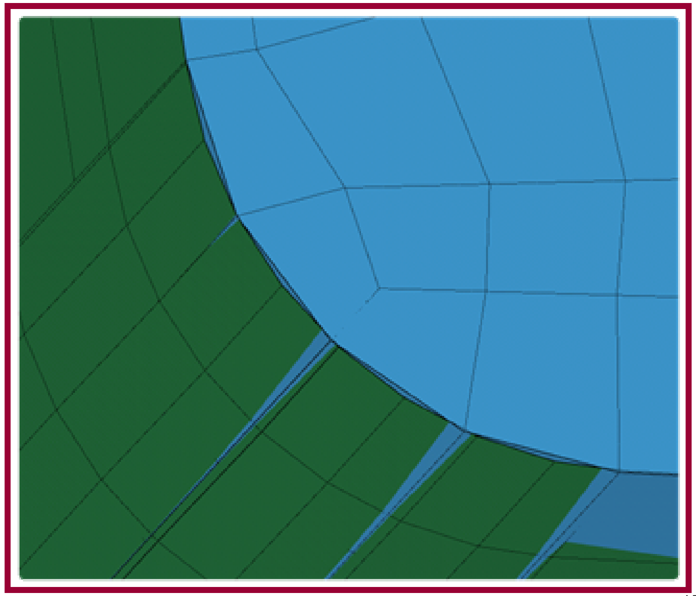
```
*CONTACT_TIED_SURFACE_TO_SURFACE_OFFSET_THERMAL_ID
$      CID     CONTACT INTERFACE TITLE
         6Punch 2-21
$     SSID      MSID     SSTYP     MSTYP    SBOXID    MBOXID       SPR       MPR
         2        21         3         3                             1         1
$       FS        FD        DC         V       VDC    PENCHK        BT        DT

$      SFS       SFM       SST       MST      SFST      SFMT       FSF       VSF

$        K      HRAD     HCONT      LMIN      LMAX      CHLM   BC_FLAG     1_WAY
               &HTOOL            5.000     5.000
```

Set HTOOL to a very high number to get a thermal equivalent to tied contact

HTOOL ~ 50.000 W/m²K

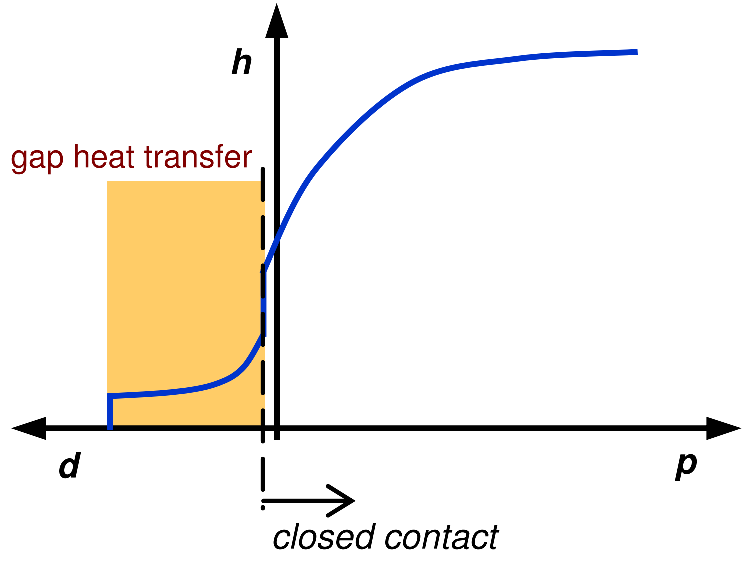


How to model gap heat transfer ?

$$h_{gap} = \frac{k}{L_{gap}} + f_{rad}(T + T_\infty)(T^2 + T_\infty^2)$$

very sensitive to small gaps

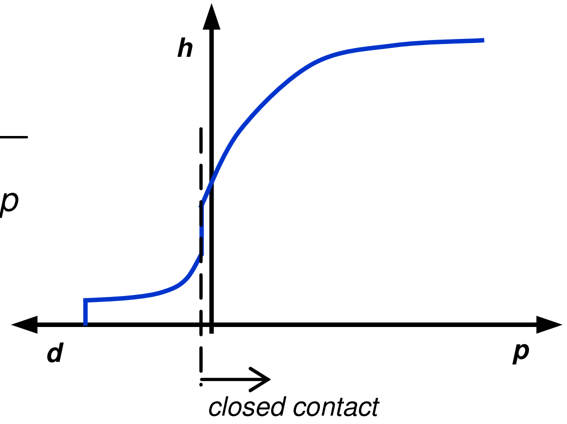
Kelvin scale necessary



⇨ **do not use radiation term with °C scale**

How to model gap heat transfer ?

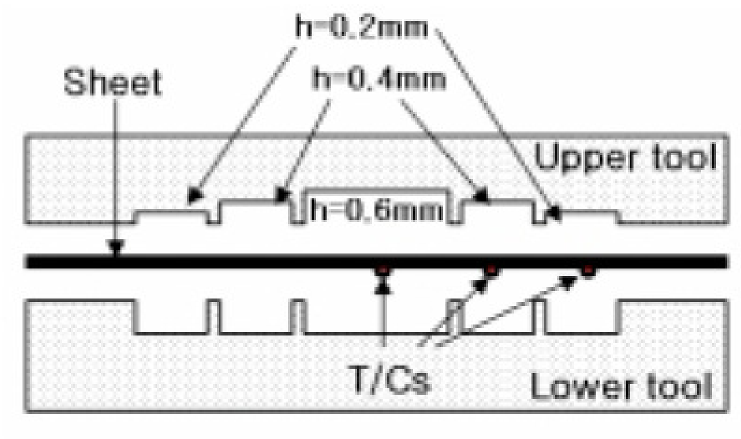
$$h_{gap} = \frac{k}{L_{gap}}$$

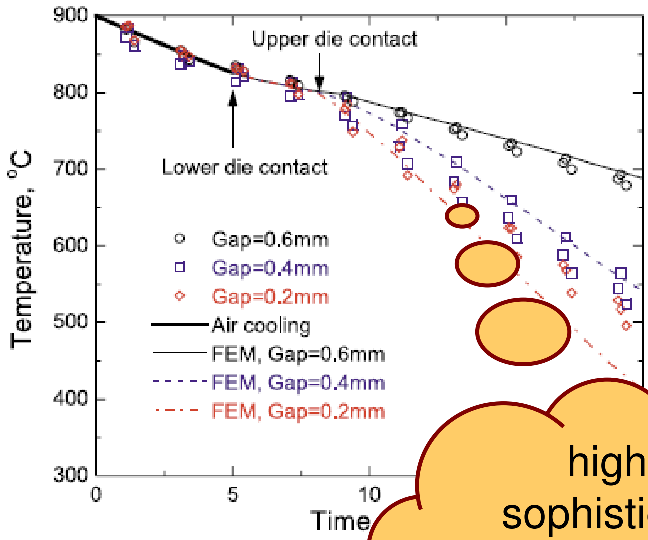


POSCO TECHNICAL REPORT 2006(VOL. 10 No. 1)

DEVELOPMENT OF THERMAL-MECHANICAL COUPLED SIMULATION SKILLS FOR HOT PRESS FORMING TOOL DESIGN

H. G. Kim*, H. S. Son and S. H. Park



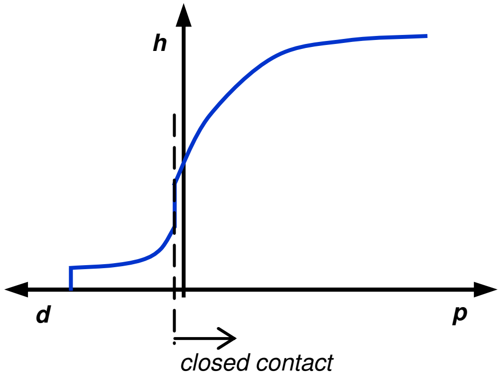


k = 0.10 W/mK

higher sophisticated formulation may give better agreement

How accurate is gap heat transfer ?

$$h_{gap} = \frac{k}{L_{gap}}$$



European standard EN 10143

Table 4: Thickness tolerances: EN 10143 : 2006: $R_{p0.2} \geq 360 N/mm^2$ and $\leq 420 N/mm^2$

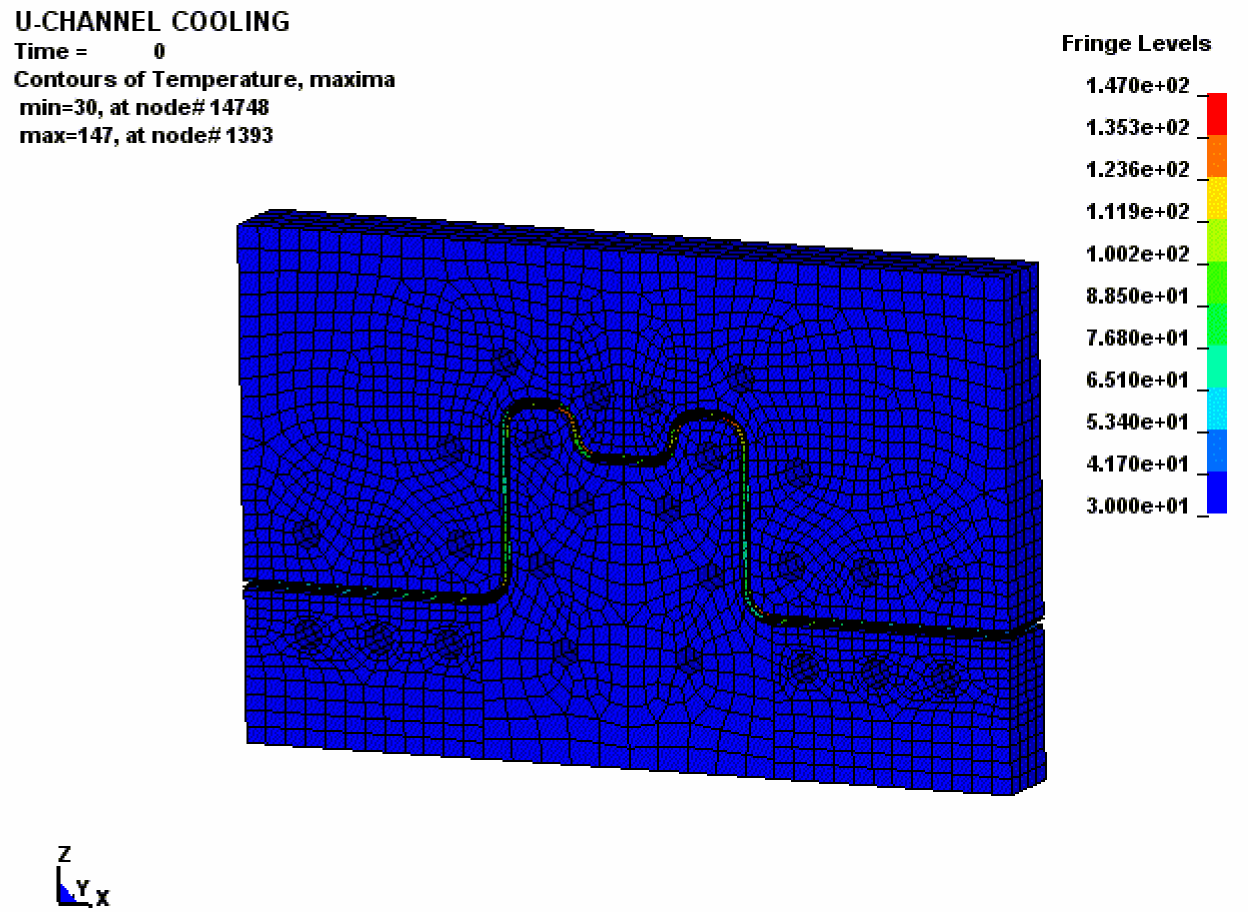
Nominal thickness		Normal tolerances for a nominal width of			Special tolerances (S) for a nominal width of		
		≤1200	>1200 ≤1500	>1500	≤1200	>1200 ≤1500	>1500
>	≤	±	±	±	±	±	±
0.35	0.40	0.05	0.06	0.07	0.040	0.045	0.050
0.40	0.60	0.06	0.07	0.08	0.045	0.050	0.060
0.60	0.80	0.07	0.08	0.09	0.050	0.060	0.070
0.80	1.00	0.08	0.09	0.11	0.060	0.070	0.080
1.00	1.20	0.10	0.11	0.12	0.070	0.080	0.090
1.20	1.60	0.13	0.14	0.16	0.080	0.090	0.110
1.60	2.00	0.16	0.17	0.19	0.090	0.110	0.120
2.00	2.50	0.18	0.20	0.21	0.120	0.130	0.140
2.50	3.00	0.22	0.22	0.23	0.140	0.150	0.160

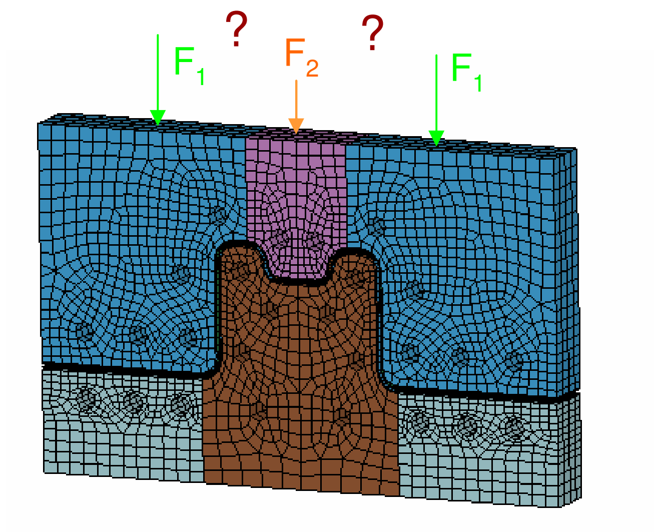
nominal thickness of Numisheet BM3 1.95 mm

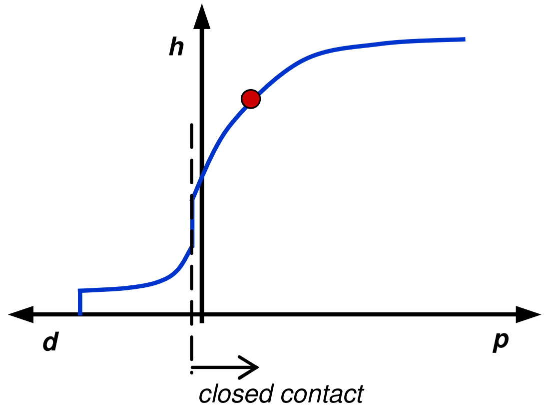
USIBOR as delifered $R_{p0.2}$ = 350…550 MPa

- ⇨ uncertainty in nominal thickness has strong impact
- ⇨ higher sophisticated formulations overstate second order effect of gap heat transfer

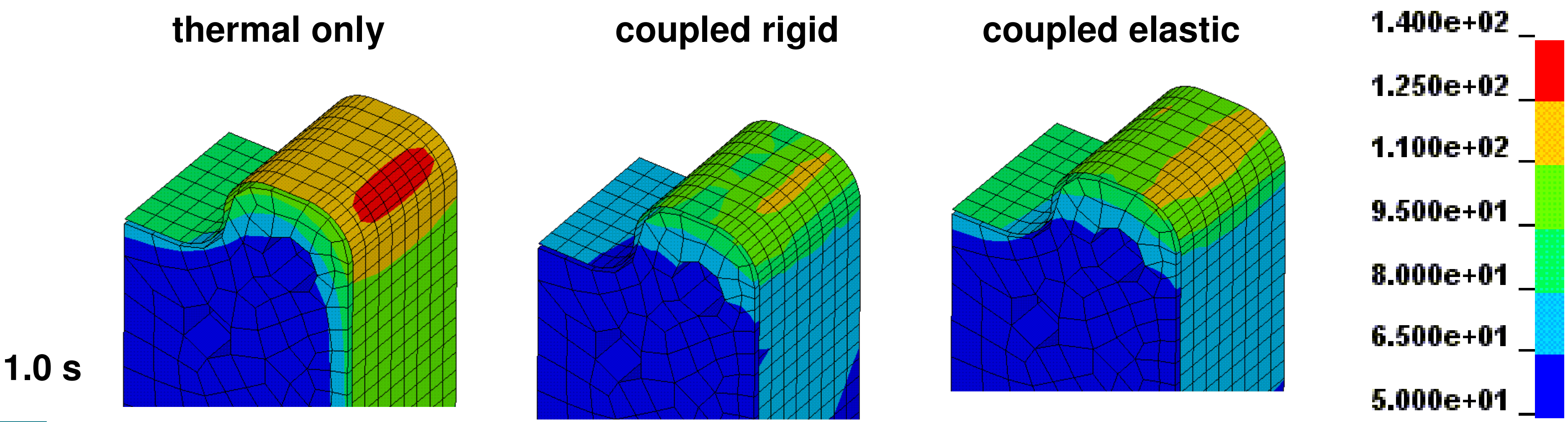
Cooling Simulation Solution Methods



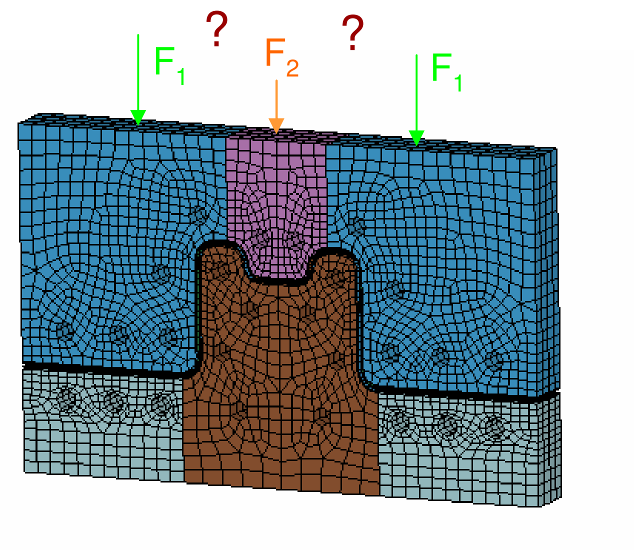


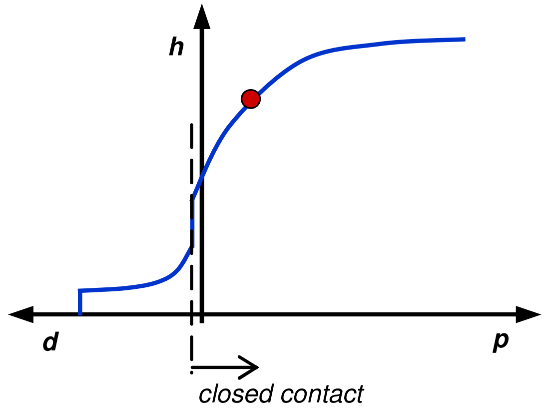


? elastic or rigid dies ?

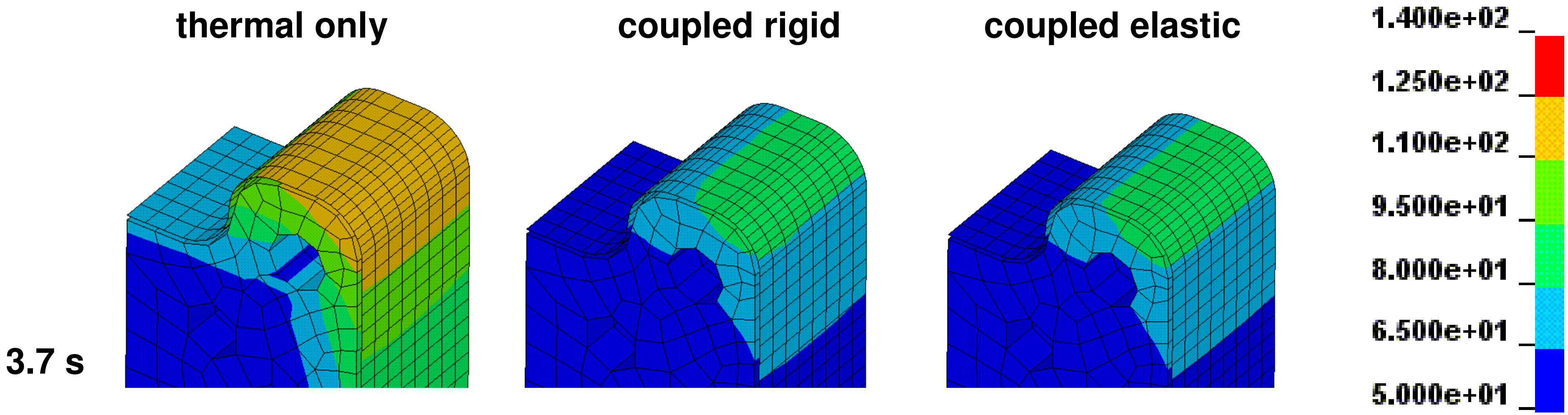


Cooling Simulation Solution Methods





? Elastic or rigid dies ?



Questions ?

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