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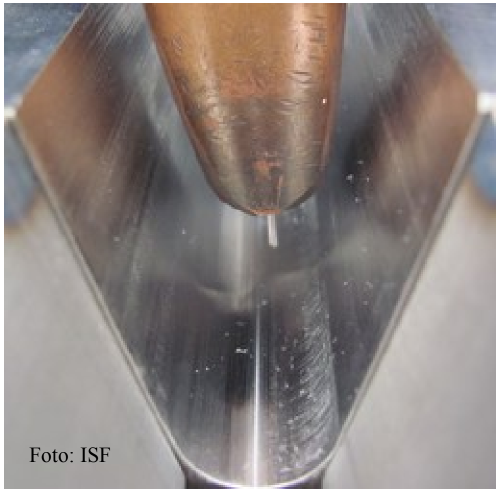

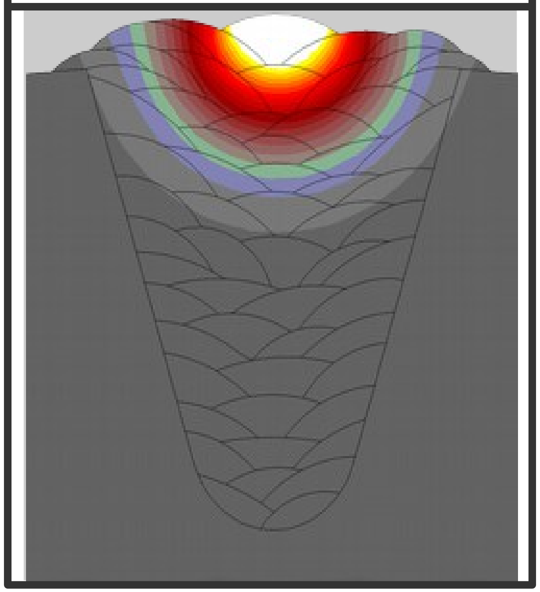

Equivalent Energy Method for Welding Structure Analysis

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From the manufacturing specification
to the simulation model

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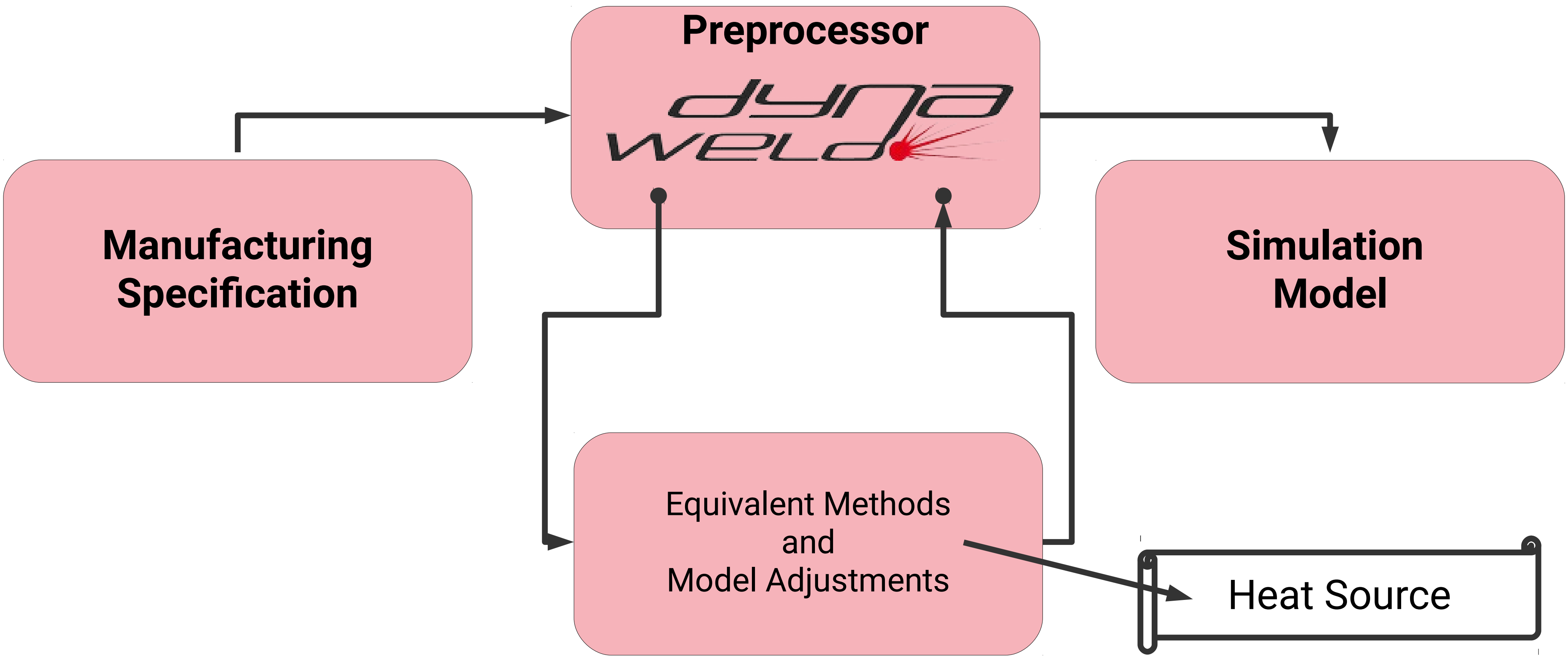
Motivation

Automation as far as possible - input by hand as less as possible
Information of manufacturing specification provide the data for the simulation model



LS-DYNA:

- Finite-Element-Code with many solvers and methods but one Code
- Enables continous process chain simulation within one data-structure
- Welding Simulation uses thermal, mechanichal and electromagnetic solver

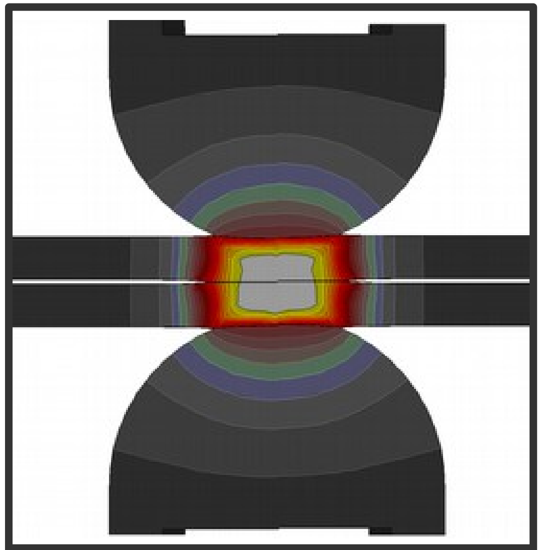
DynaWeld:

- Preprocessor for welding and heat treatment analysis with the LS-DYNA Code
- Environment to launch auxillary software needed for simulation setup
- Provides automatisations to speed up the model setup and post processing

DynaWeld **LS-DYNA**

Welding Process Analysis:

- predictive calculation of heat input
- predictive calculation of weld pool evolution
- for fusion welding uses CFD approaches
- for resistive welding uses FEM thermal-mechanical-electromagnetic coupled analysis
- Scope of analysis → **weld pool**

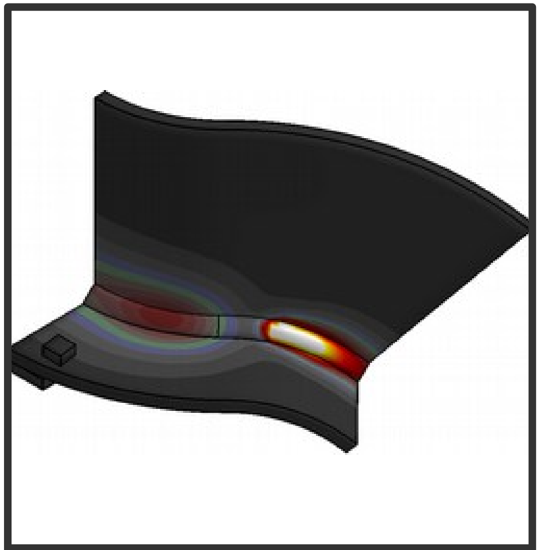


Welding Structure analysis:

- heat input by equivalent time-space function of heat density
- heat input as equivalent load but not predictive clculated
- uses FEM thermal-mechanical coupled analysis
- Scope of analysis → **entire assembly**

Transient:

- Moving heat source
- Temperature gradient in three dimensions and time
- 3D Analysis
- Takes into account heating, cooling and the temperature - time evolution



Metatransient:

- Simplified approach to speed up simulation time
- heat input of a discrete lenght of the weld pass simultaneous
- No moving heat source
- Temperature gradient in weld direction neglected
- 3D Analysis or 2D Analysis
- Takes into account heating, cooling and the temperature - time evolution

Welding Procedure Specification (WPS):

- Manufacturing specification for welding
- contains all process parameter to define the process

Travel speed v_t:

- velocity of the moving torch or beam.
- Equivalent to the velocity of the moving heat source

Wire feed speed v_w:

- velocity of the welding wire exiting the torch for gas metal arc welding processes

Heat Input / Energy per unit time Q:

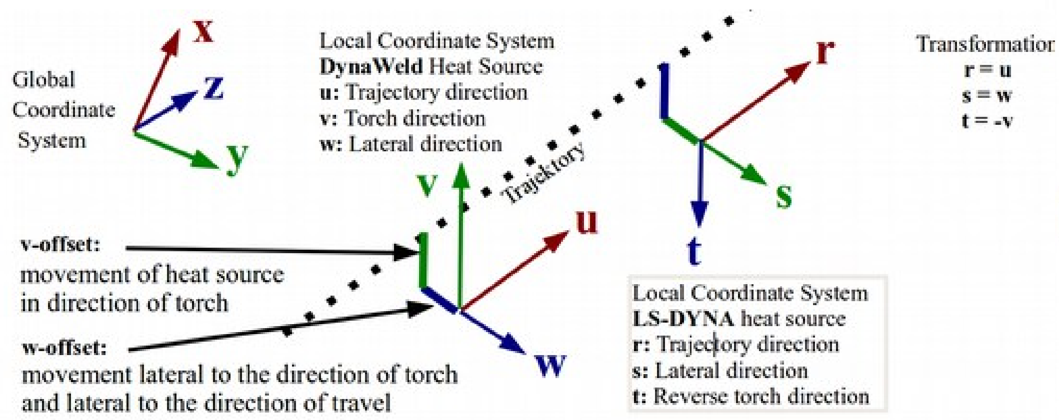
- energy per unit time which enters the workpice: $Q = U * I * \eta$ with:
  - η = 0,7 for WIG,
  - η = 0,8 for GMAW
  - η = 1,0 for SAW

Heat Input / Energy per unit length E:

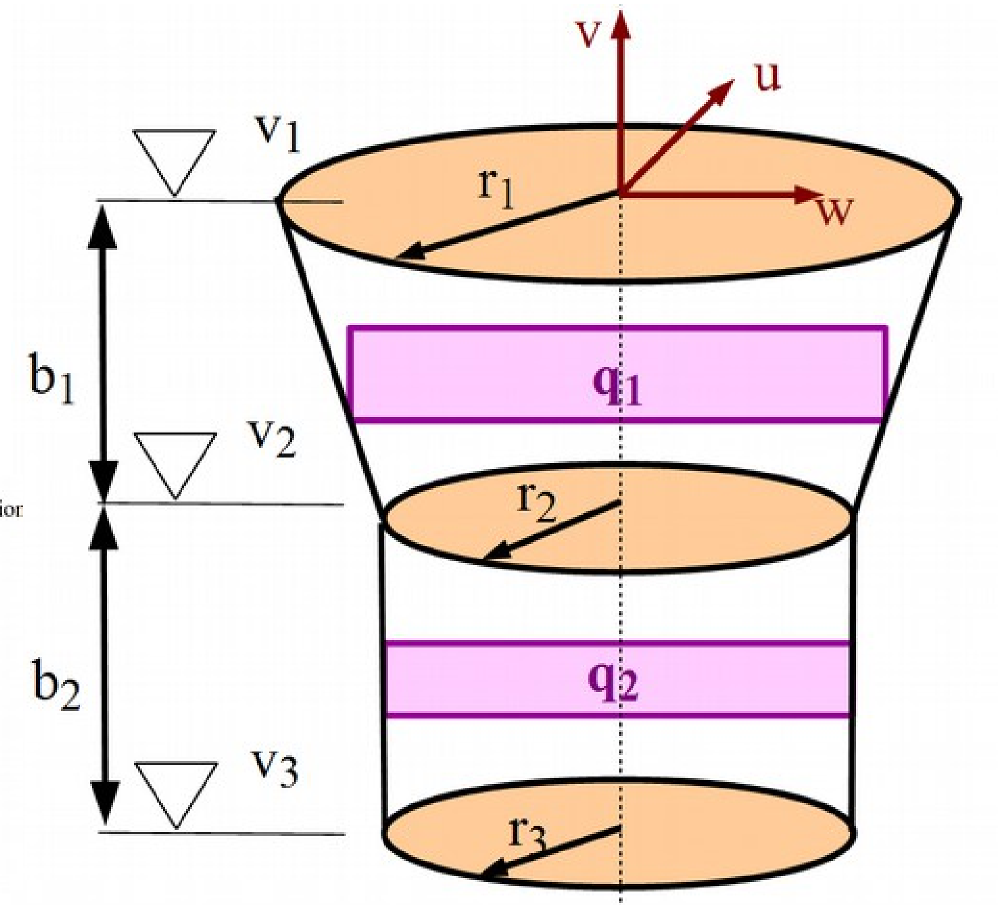
- energy per unit length which enters the workpice: $E = Q / v_t$

The **equivalent heat source** is a function of space and time for the heat input density with **geometric shape** and **density distribution** joined to a local coordinate system moving through the simulation model according the path of the heat source and does not describe the pyhsics of the heat input but its impact correctly.

Equivalent heat source = Approach of heat input



Heat source for beam and laser welding: double conus with constant heat density (Loose)



Transient Heat Source

The elipsoidal shape of heat source is mostly choosen for arc welding processes. She is divided in a front and rear part with different heat input. The spherical heat source is a trivial form of elipsoidal heat source.

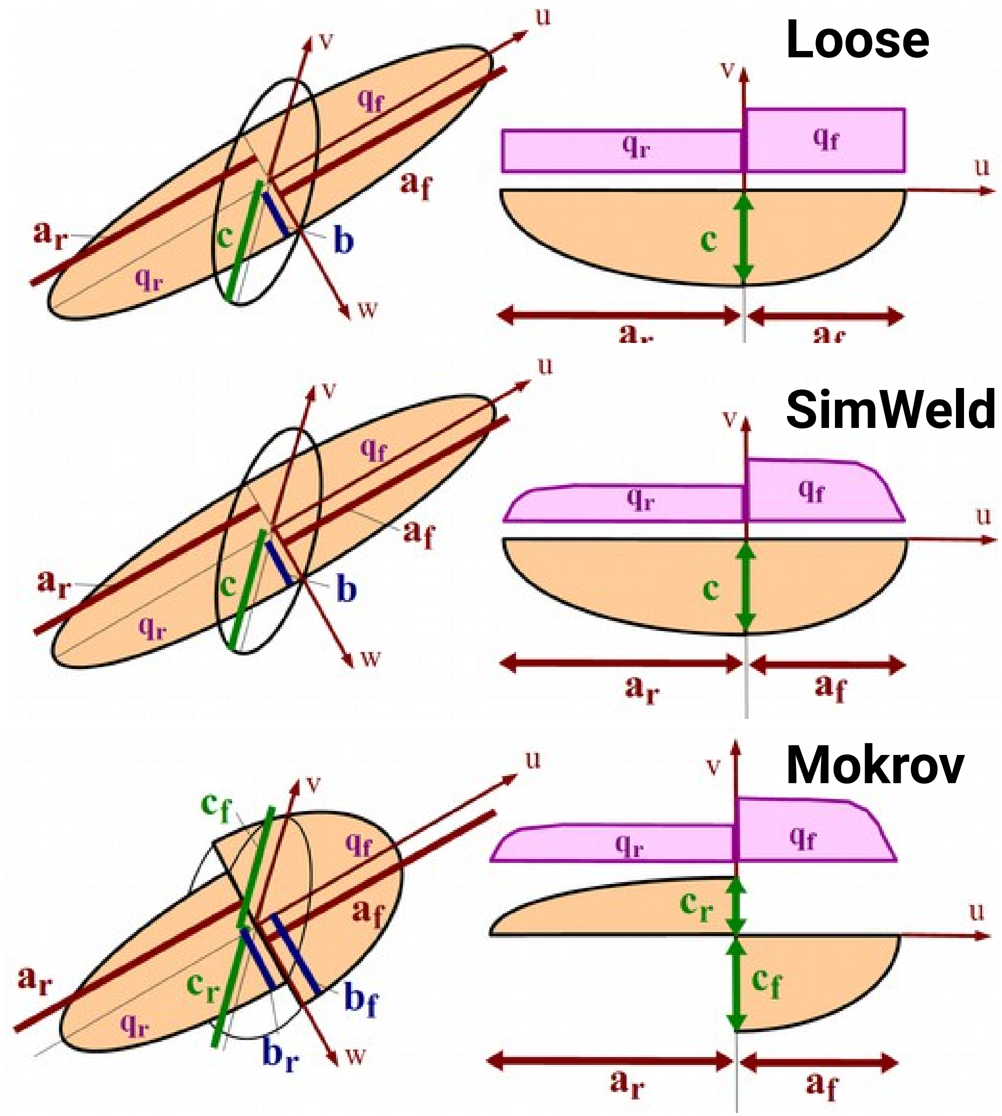
The **Loose** approach is a constant distributed heat density considering the heatconvection by flow in the melt.

The **SimWeld** approach uses for this a super gauss function. Compared to Loose the SimWeld function provides a steady mathematical function

The **Mokrov** approach considers an upper heat input in the rear part. This fits better the real melt pool shape for GMAW.

The heat input per unit time is the integral of heat density over heat source geometry: $Q = \int_V \cdot q$

Vice versa the heat density is tetemined by the heat input per unit time and the distribution function.

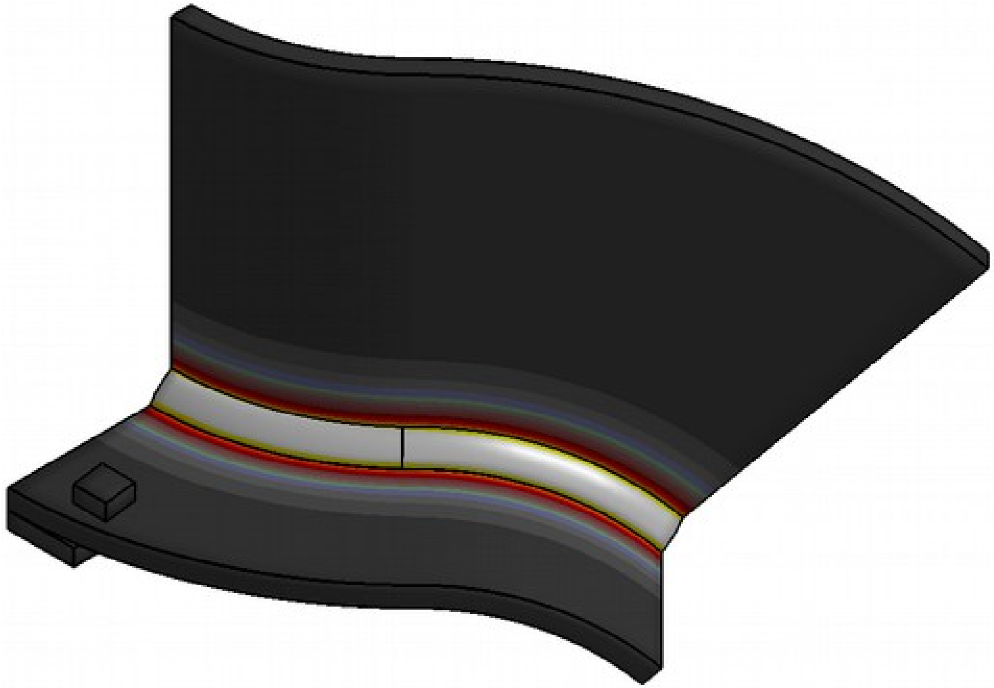


For the metatransient analysis elements are heated with constant heat density multiplied by function of time: $q = f(t)$.

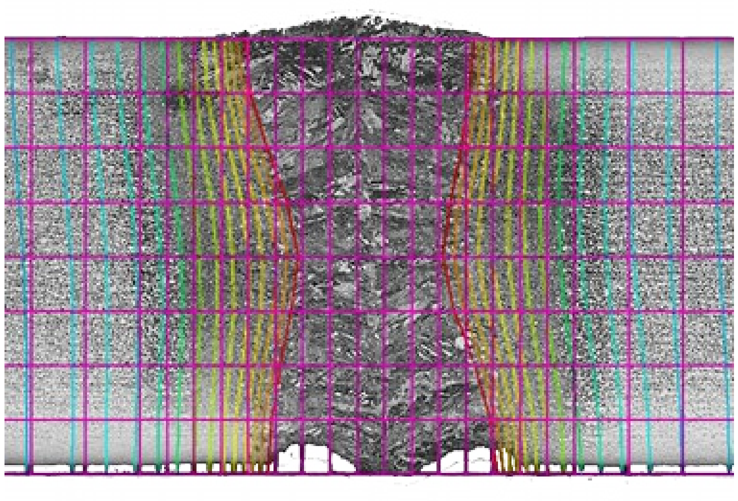
With the part heat source all elements of the part are heated simultaneous.

The part represents one layer, one pass or sections of it to achieve a successive closing of the weld.

The heat input per unit time is the product from part volume and heat density: $Q = V \cdot q$

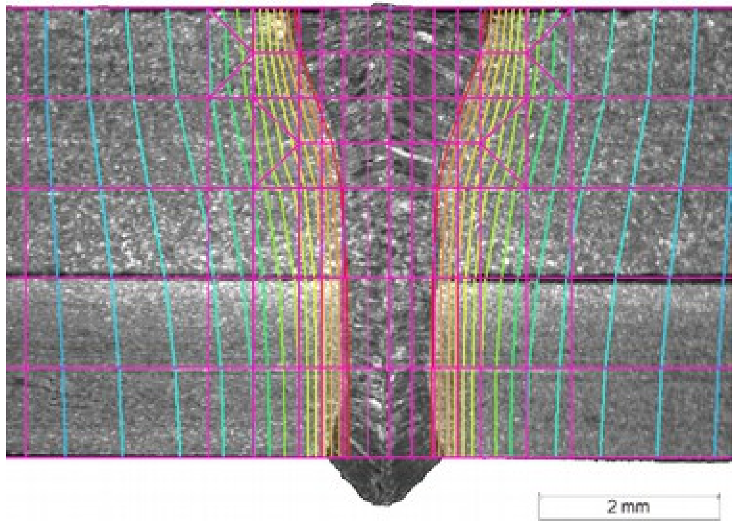


In case of unknown heat input the only way of heat source adjustment is the adjustment by macro section or known shape of the melt pool. For laser or beam weld the heat input is mostly unknown because of unknown variety of efficency.



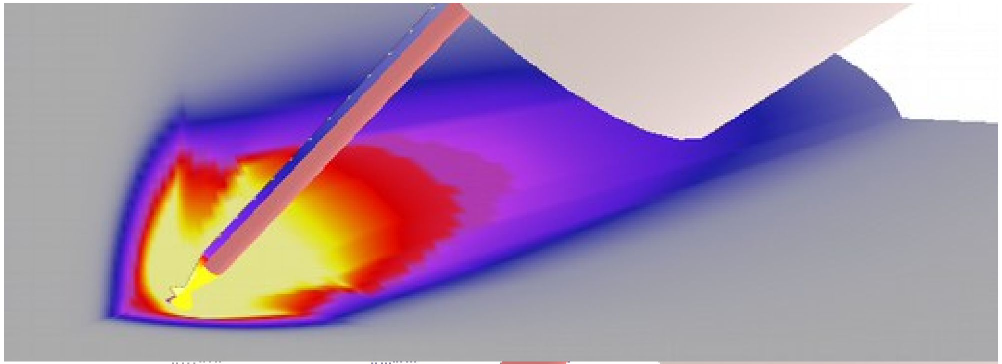
Workflow:

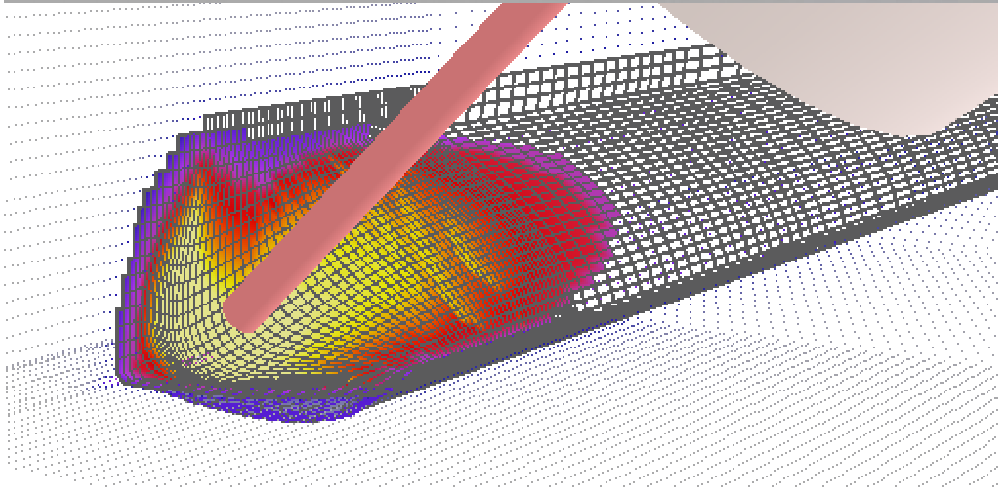
- Set heat source geomettry similar to melt pool shape
- Calculation of temperature field with start value of heat input.
- Adjustment of heat input til the calculation fits the target.



Heat Source from Process Simulation

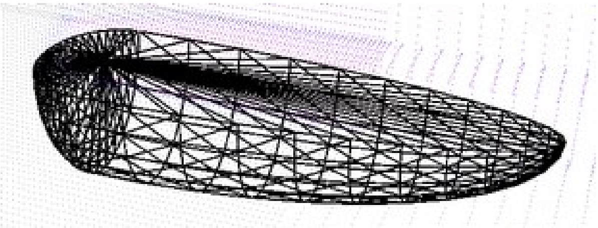
As the process simulation is the determinend calculation to predict the heat input a special postprocessing may provide the parameter of the equivalent heat source.

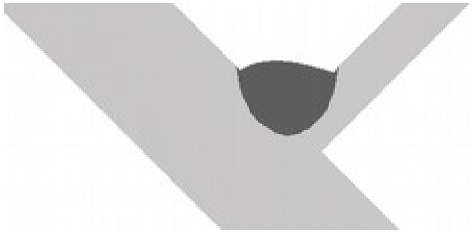




SimWeld provides the paramer for SimWeld or Mokrov elipsoidal heat source for gas metal arc welding:

```
SimWeld MR10 equivalent heat source
8074,89890  //Q [W]
5348,47510  //Qf [W]
2726,42380  //Qr [W]
3,25000  //af [mm]
21,87500  //ar [mm]
4,30674  //b [mm]
5,95269  //c [mm]
3,01596  //x0 [mm]
3,01596  //z0 [mm]
45,00000  //ay [degree]
60,00000  //vy [cm/min]
1,32472  //factor_front
0,67528  //factor_rear
```





The heat source parameters can be developed from the welding procedure specification (WPS) for the following welding processes:

- arc welding
- gas metal arc welding (GMAW)
- tungsten inert gas welding (TIG)
- submerged arc welding (SAW)

The WPS is the technical description of the weld process and its parameter specified in ISO 15609. The parameters to be extracted from the WPS are:

- Current (I),
- Voltage (U)
- travel speed (v_t)
- shape or dimension of the pass.
- wire feed speed (v_w) used to calculate the area of the additional material.

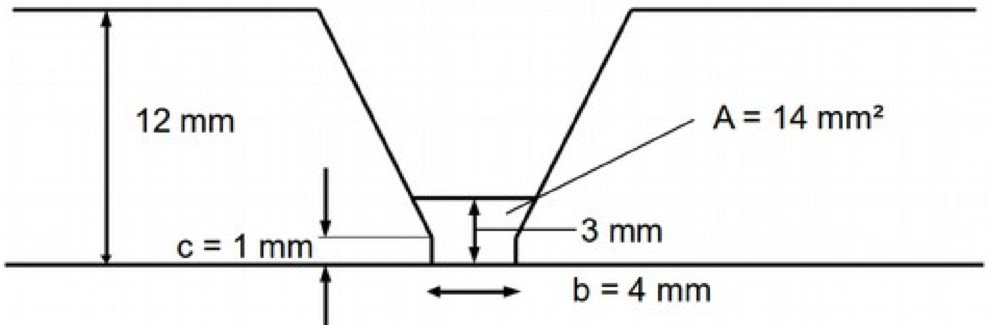
Rule of thumb for the parameter of elipsoidal heat source:

- weighting between front and rear: $f_f = 1{,}2$ and $f_r = 0{,}8$
- weighting between the longitudinal radii: between $a_r = a_f$ and $a_r = 2\,a_f$
- the elipsoid of the heat source should get the same dimensions as the melt pool.
- b (half width) and c (depth) → filler geometry or the specified dimension of the pass.
- $a_f > b$, $a_f > c$ and ai has to be larger than one element length.

Given is the WPS for a V-shaped multi pass butt weld of a tube with 12 mm wall thickness.

Gap b = 4 mm

Root face c = 1 mm

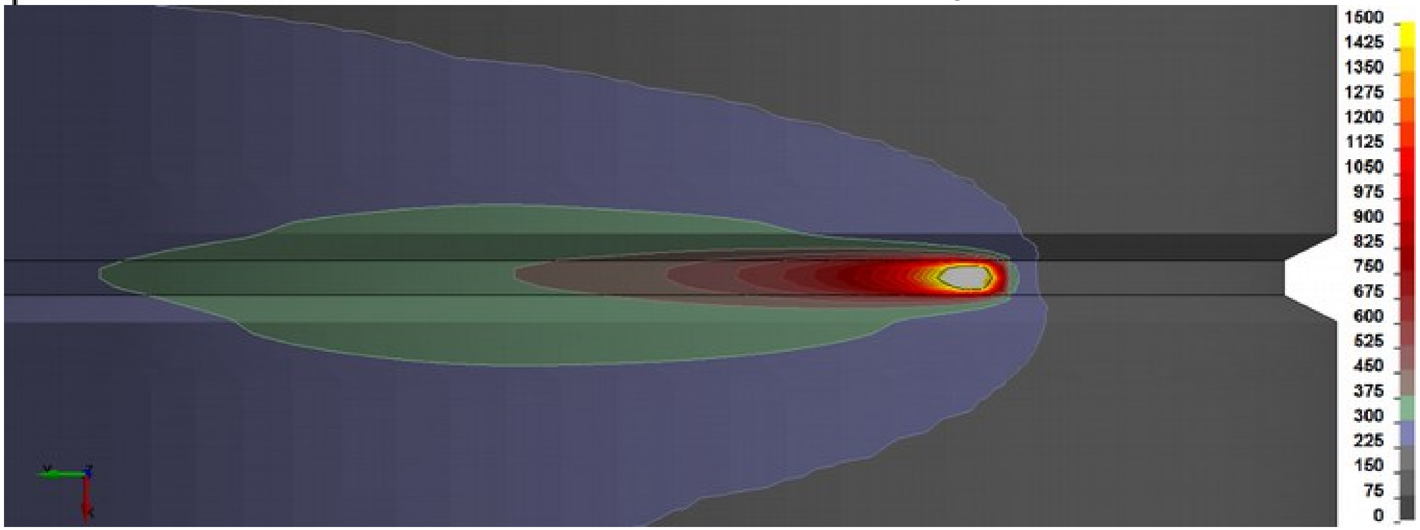


The groove weld pass has the following parameters (GMAW):

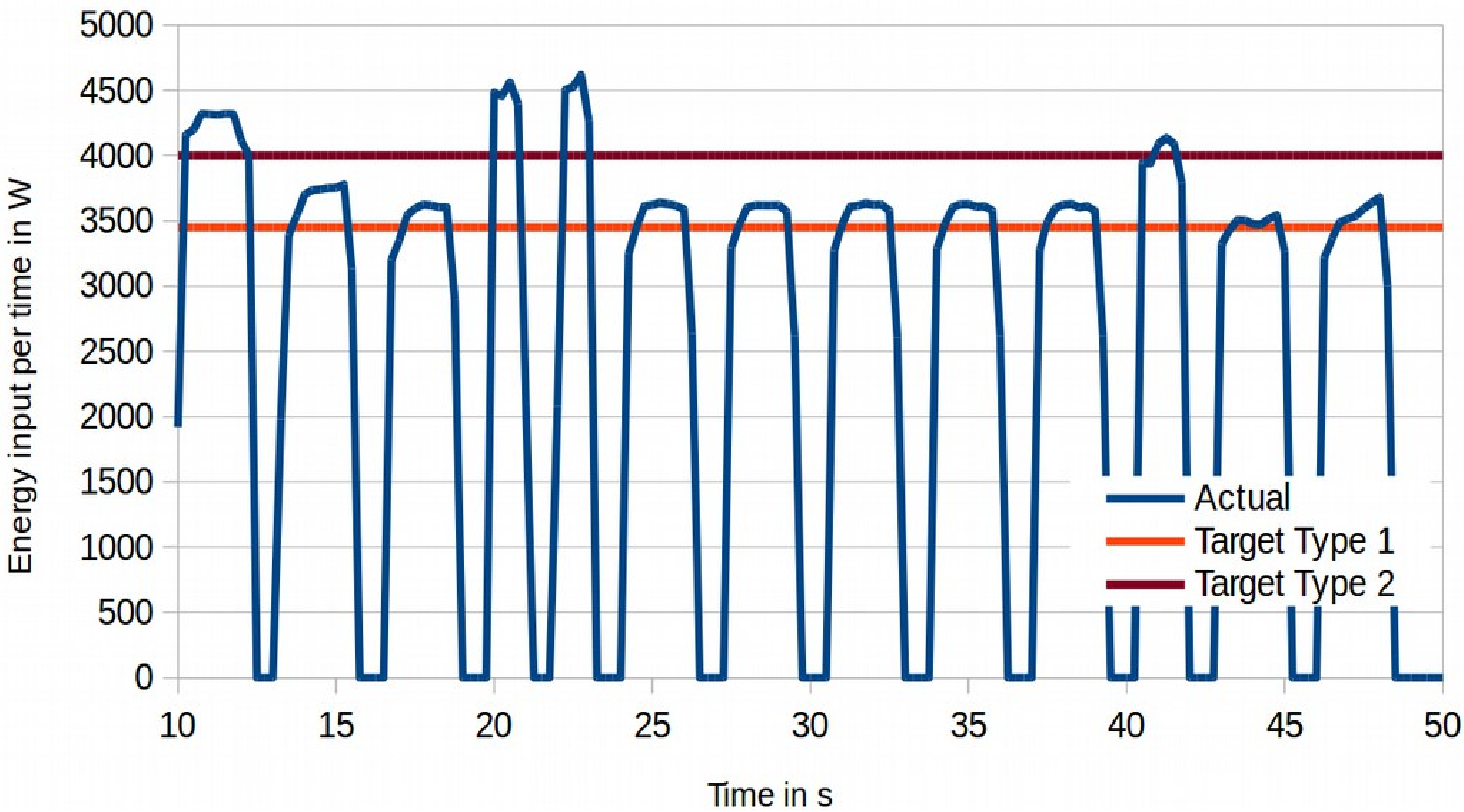
Travel speed:	v_t = 19,2 cm/min = 3,2 mm/s
Voltage:	U = 19 V
Current:	I = 80 A
Wire feed speed	v_W = 3,5 m/min = 58,3 mm/s
Wire diameter	D_W = 1 mm

$$Q = U \cdot I \cdot \eta = 19\,V \cdot 70\,A \cdot 0{,}8 = 1216\,W$$

$$A = \frac{v_w}{v_t} \cdot \frac{\pi}{4} D_w^2 = \frac{58{,}3\,\frac{mm}{s}}{3{,}2\,\frac{mm}{s}} \frac{\pi}{4} 1{,}0^2\,mm^2 = 14\,mm^2$$



Heat Input Control



The **E**quivalent **E**nergy **M**ethod postulates:

- the heat input in the metatransient simulation is the same as in the transient simulation and the same as in reality.

As the transient evolution is neglectect not the
heat input per unit time $Q = U * I * \eta$
but the
heat input per unit length $E = Q / v_t$
comes in force to determine the overall heat input.

The heat input is designed on the volume of deposit material of the pass.

For the design of the heat source parameter q (heat input density per unit time)
the heat input per unit length and the area A of the pass is needed,
the runtime t_r has to be calibrated.

Heat input density per unit length: $e = E / A$

Heat input density per unit time: $q = e / t_r$

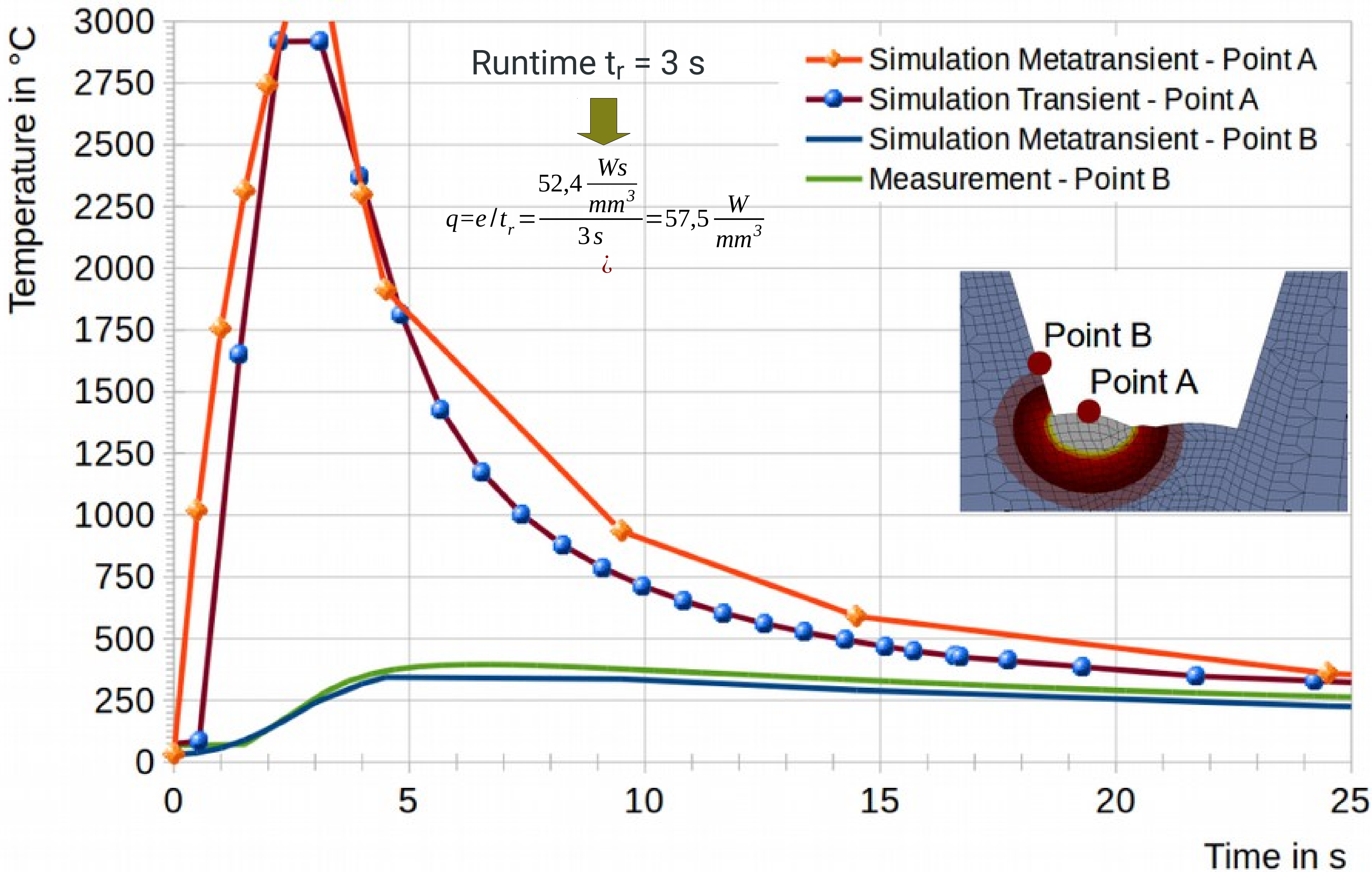
Example:

U-grooved longitudinal weld of a tube
Inconel, Alloy 617 / Nicrofer 5520
GMAW with 60 passes
Metatransient analysis, 2D

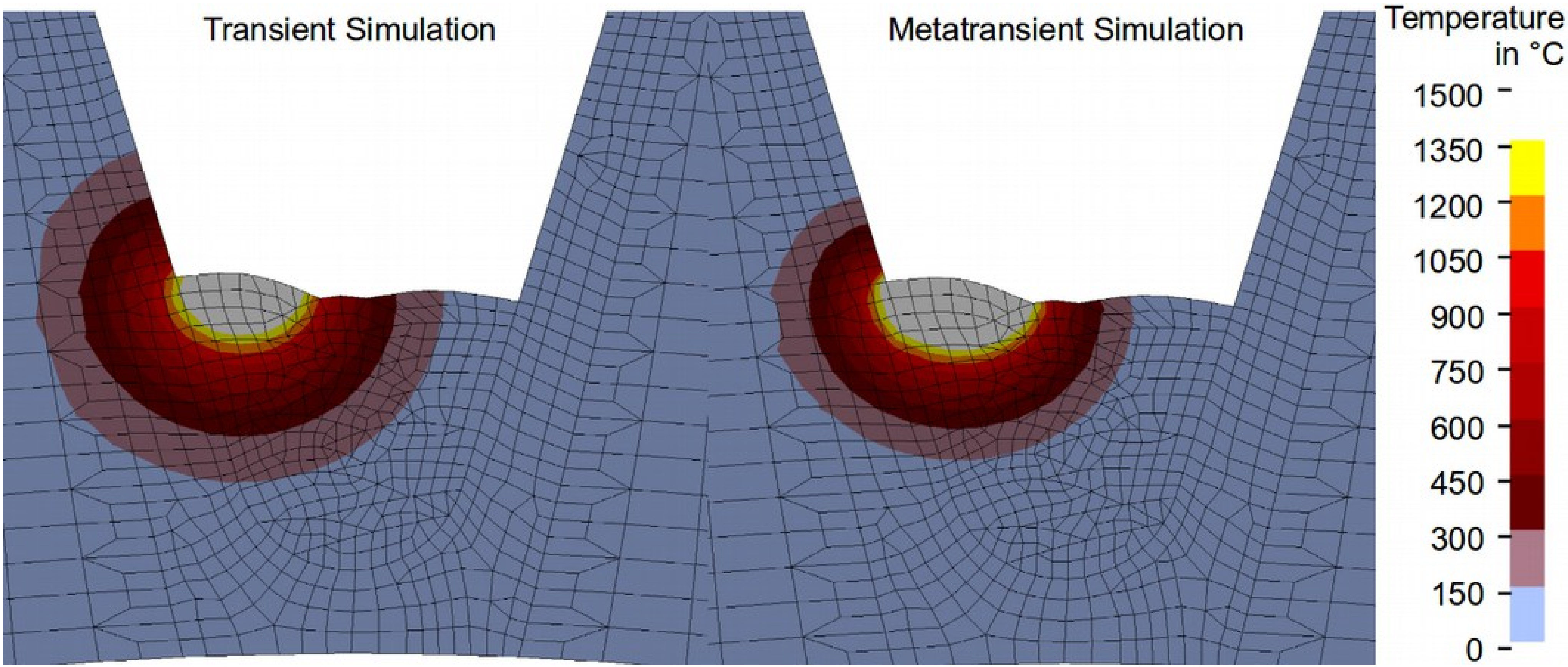
The area A of each pass has to considered:
A = 14,3 mm²
E = 750 Ws/mm = 7,5 kJ/cm

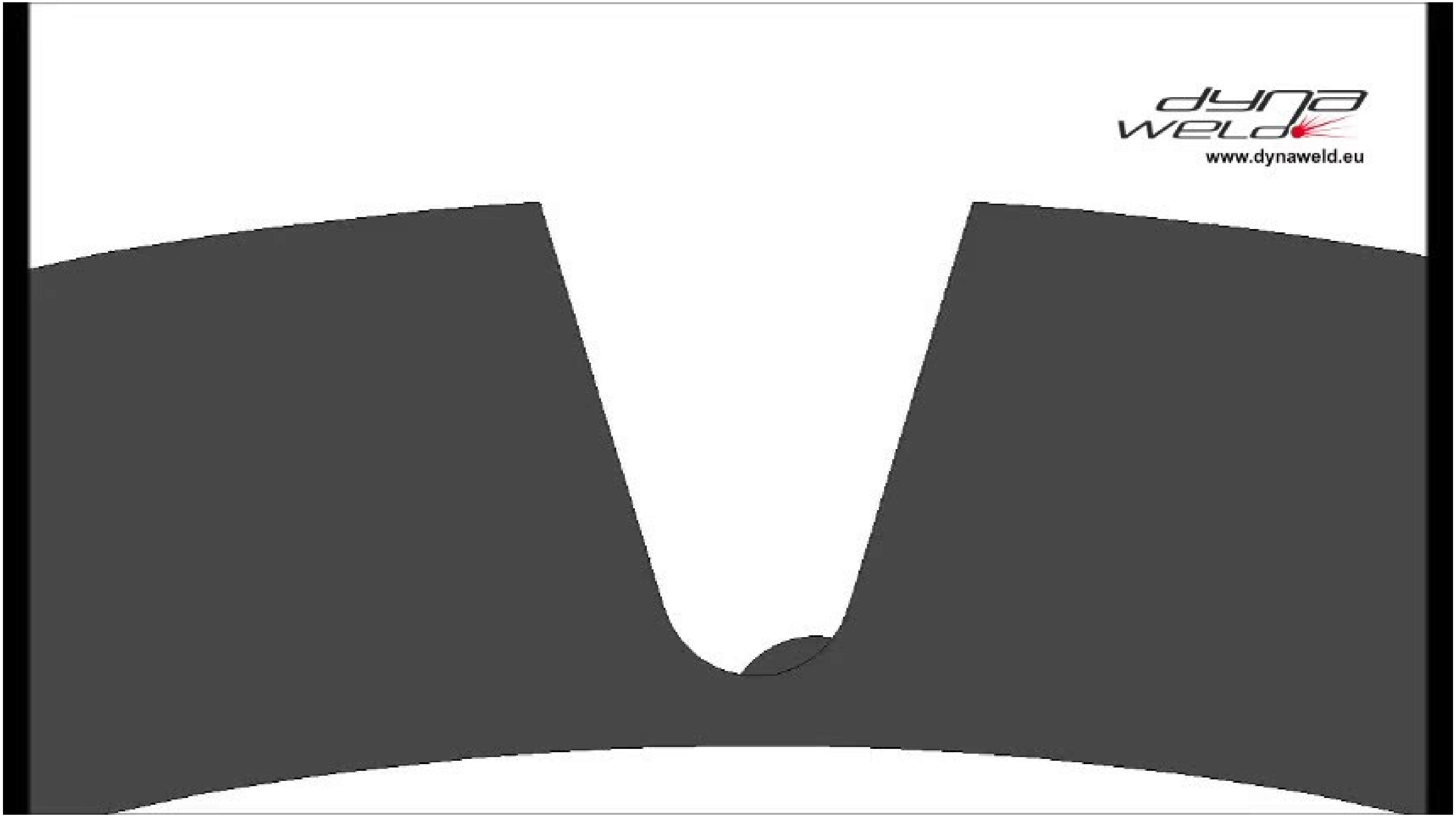
$$e = E / A = \frac{750 \frac{Ws}{mm}}{14{,}3\, mm^2} = 52{,}4 \frac{Ws}{mm^3}$$

Adjustment runtime
Simulation - Measurement



Comparision Transient - Metatransient

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