

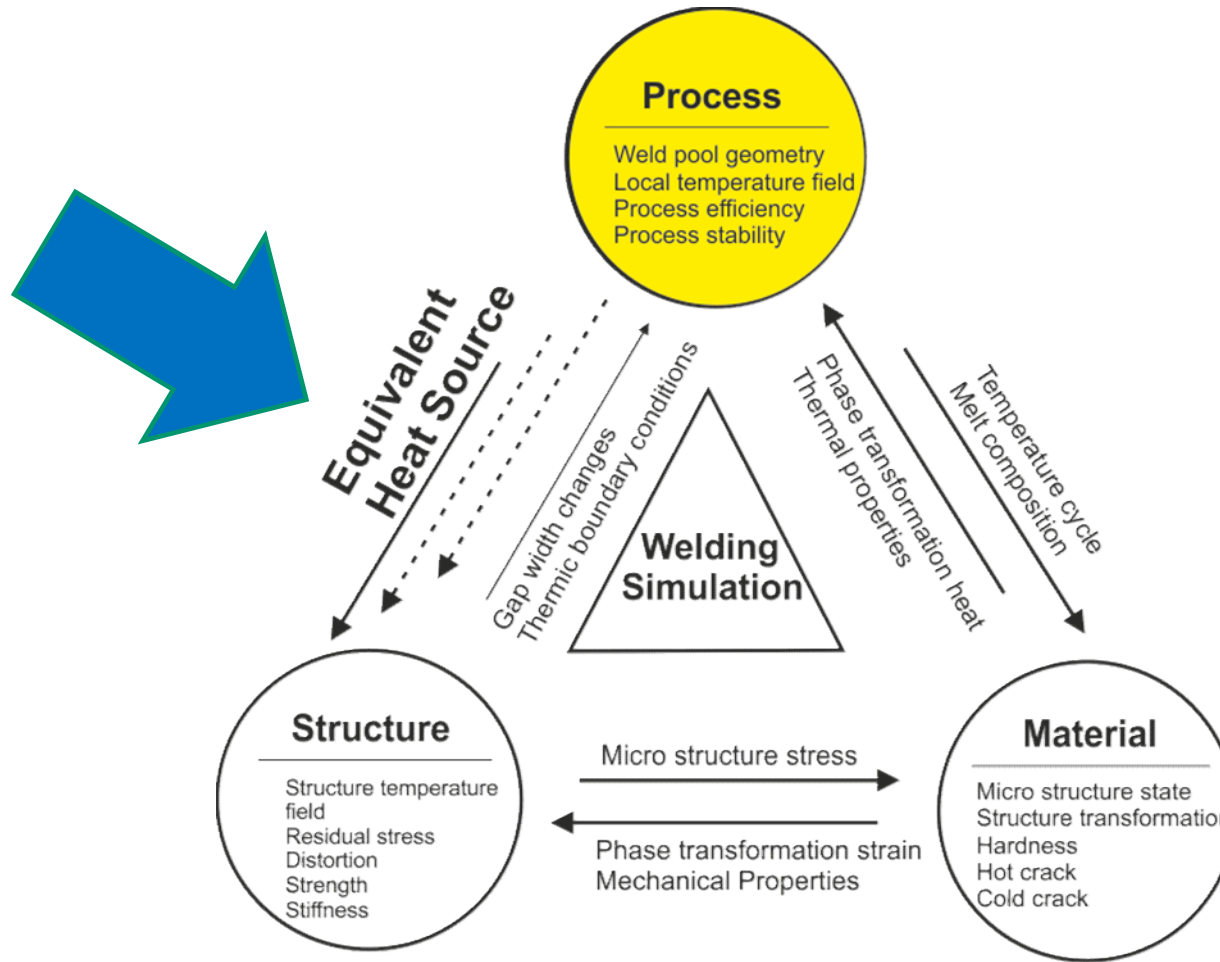
**27. September 2016, Aachen
Infotag Schweißen und Wärmebehandlung**

**SimWeld – Neue Entwicklungen und präzisere Modelle der
Ersatzwärmequelle für die Struktursimulation**

O. Mokrov

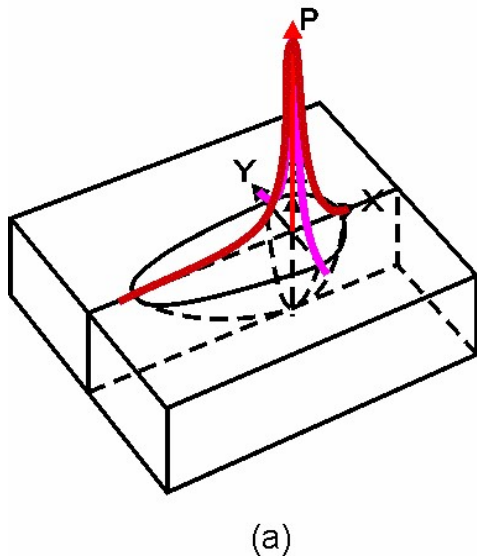
Inhalt

- Ersatzwärmequelle Schweißsimulation
- Äquivalente Wärmequelle nach Goldak
- Modifikation Phase 1 (mathematisch)
- Modifikation Phase 2 (mathematisch und geometrisch)
- Simulationsbeispiele
- Simulation der Schweißprozesses mit **SimWeld**
- Berechnung einer äquivalente Wärmequelle mit **SimWeld**



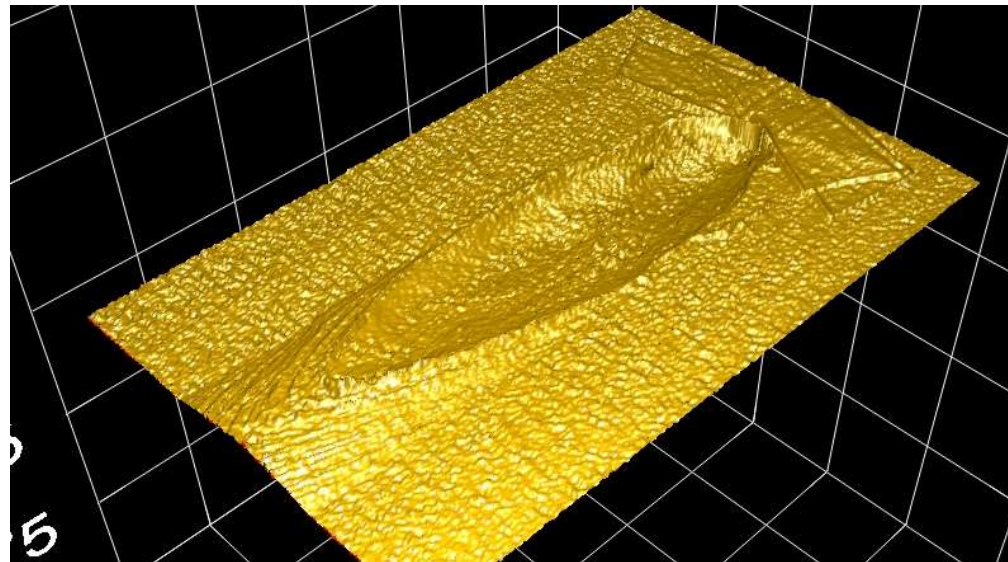
Radaj, 2002

ÄWQ nach Goldak



Eigenschaften

- Volumenquelle
- Wärmeverteilung gaussförmig, weil der Schweißprozess als eine Aneinanderreihung von statistischen Prozessen verstanden wird
- Unterschiedliche Parameter in der vorderen und hinteren Hälfte
- Relativ gute Übereinstimmung bei geringen Schweißströmen



■ ÄWQ nach Goldak

■ forward

$$q_f(x,y,z,t) = \frac{6\sqrt{3}f_f Q}{a_f b c \pi \sqrt{\pi}} \exp\left(-3\frac{(x+v(\tau-t))^2}{a_f^2}\right) \exp\left(-3\frac{y^2}{b^2}\right) \exp\left(-3\frac{z^2}{c^2}\right)$$

■ rear

$$q_r(x,y,z,t) = \frac{6\sqrt{3}f_r Q}{a_r b c \pi \sqrt{\pi}} \exp\left(-3\frac{(x+v(\tau-t))^2}{a_r^2}\right) \exp\left(-3\frac{y^2}{b^2}\right) \exp\left(-3\frac{z^2}{c^2}\right)$$

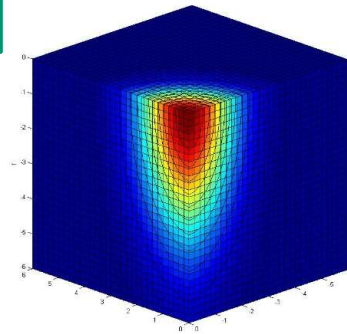
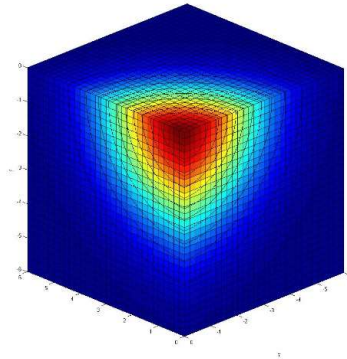
$$c = 3; \quad k_x = \frac{c}{a_x^2}; \quad k_y = \frac{c}{b_y^2}; \quad k_z = \frac{c}{c_z^2}; \quad d = (a_x \cdot b_y \cdot c_z) \pi^{1.5};$$

$$KG = \frac{2c^{1.5}}{d}$$

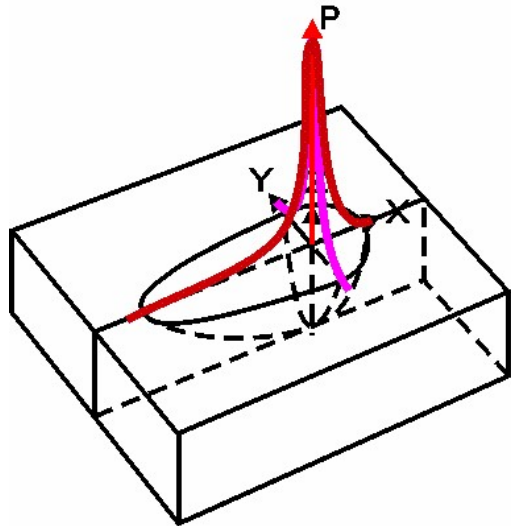
$$f_{Gol}(x,y,z,t) = KG \exp\left(-\left((x_0 + v(\tau-t))^2 k_x + y^2 k_y + z^2 k_z\right)\right)$$

■ R^2 für äquivalente Verteilung

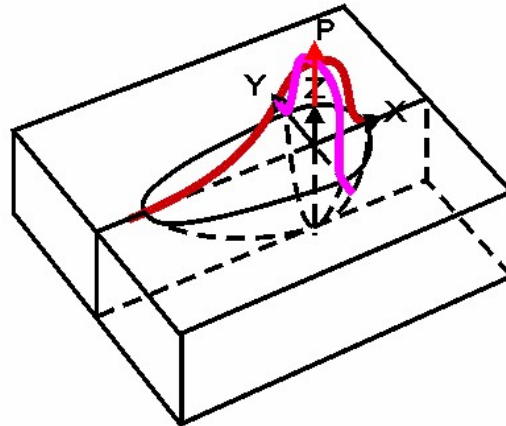
$$f_{Gol}(x,y,z,t) = KG \exp\left(-\left(kR^2\right)\right)$$



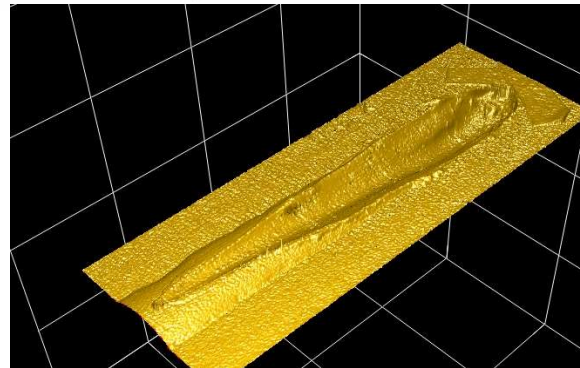
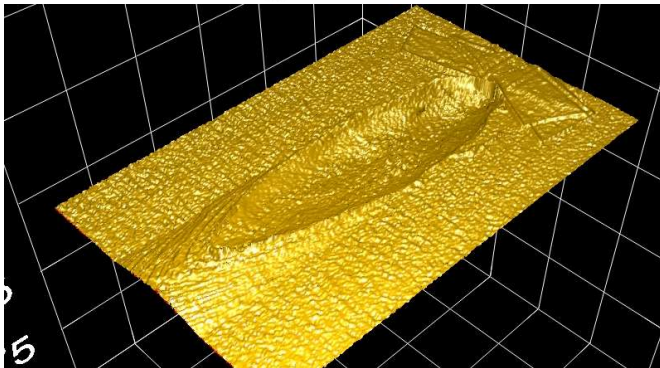
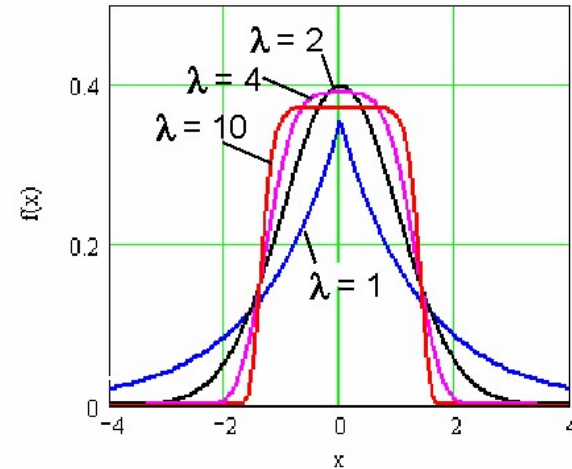
ÄWQ nach Goldak



modifizierte ÄWQ



1D-Verteilungsfunktion für verschiedene Formparameter



$$f(x) = \alpha \exp \left(- \left(\frac{|x - \theta_0|}{\sqrt{2\theta_1}} \right)^{\lambda} \right)$$

RykalinC3Gaus2D_Funktion

MR4_C1_SuperGaus2D_Funktion

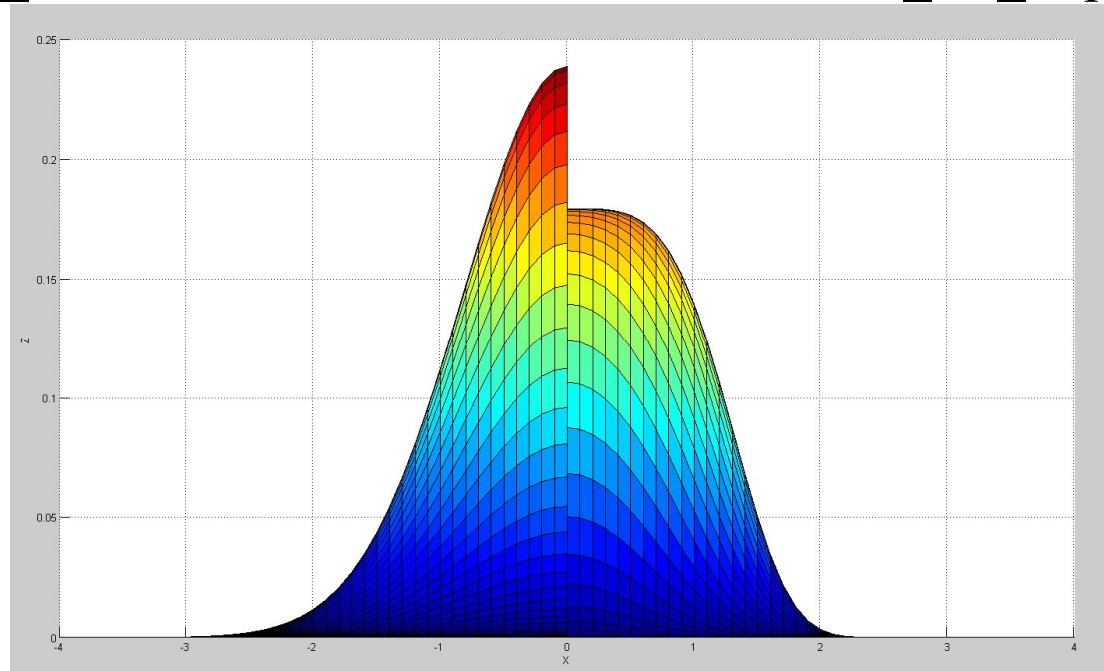
▪ Konstanten:

$$r_x = r_y = 2;$$

$$c = 3;$$

$$k = \frac{c}{r_x \cdot r_y};$$

$$b = \pi;$$



▪ Konstanten:

$$r_x = r_y = 2;$$

$$c = 2;$$

$$k = \frac{c}{r_x \cdot r_y};$$

$$b = \frac{\pi^{1.5}}{2};$$



$$f_{Ryk}(x, y) = \frac{k}{b} \exp(-k(x^2 + y^2))$$

$$f_{MR4}(x, y) = \frac{k}{b} \exp(-(k(x^2 + y^2))^2)$$

$$\iint f_{Ryk}(x, y) dx dy = \iint f_{MR4}(x, y) dx dy = 1$$

RykalinC3Gaus2D_Funktion

MR4_C1_SuperGaus2D_Funktion

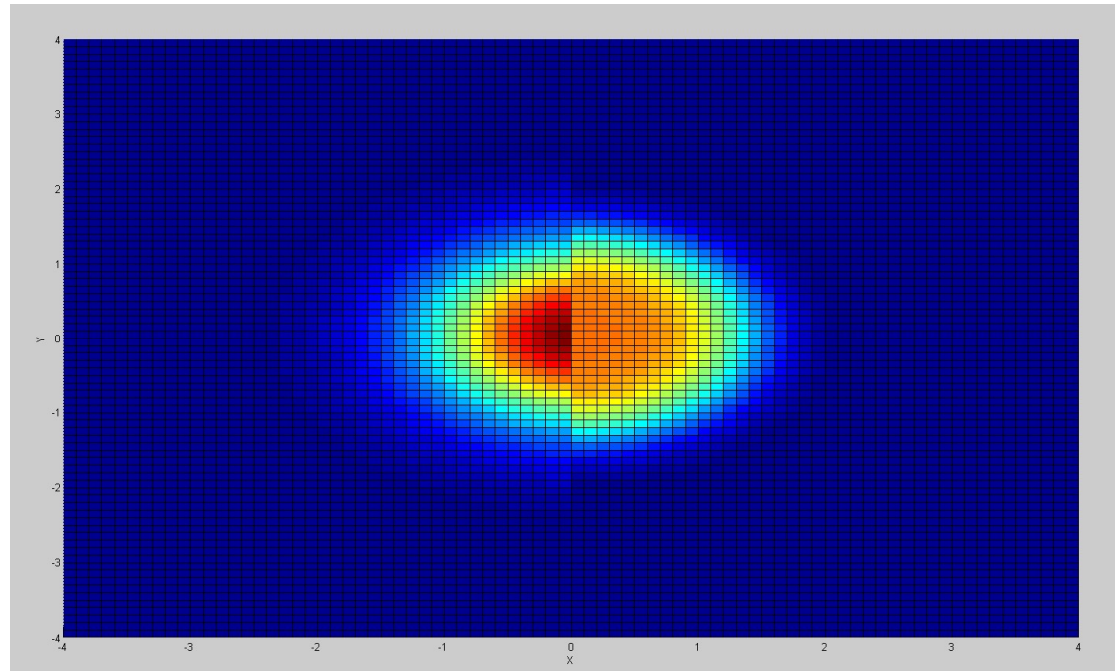
- Konstanten:

$$r_x = r_y = 2;$$

$$c = 3;$$

$$k = \frac{c}{r_x \cdot r_y};$$

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- Konstanten:

$$r_x = r_y = 2;$$

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$$f_{Ryk}(x, y) = \frac{k}{b} \exp(-k(x^2 + y^2))$$

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$$\iint f_{Ryk}(x, y) dx dy = \iint f_{MR4}(x, y) dx dy = 1$$

■ ÄWQ nach Goldak

■ forward

$$q_f(x,y,z,t) = \frac{6\sqrt{3}f_f Q}{a_f b c \pi \sqrt{\pi}} \exp\left(-3 \frac{(x+v(\tau-t))^2}{a_f^2}\right) \exp\left(-3 \frac{y^2}{b^2}\right) \exp\left(-3 \frac{z^2}{c^2}\right)$$

■ rear

$$q_r(x,y,z,t) = \frac{6\sqrt{3}f_r Q}{a_r b c \pi \sqrt{\pi}} \exp\left(-3 \frac{(x+v(\tau-t))^2}{a_r^2}\right) \exp\left(-3 \frac{y^2}{b^2}\right) \exp\left(-3 \frac{z^2}{c^2}\right)$$

$$c = 3; \quad k_x = \frac{c}{a_x^2}; \quad k_y = \frac{c}{b_y^2}; \quad k_z = \frac{c}{c_z^2}; \quad d = (a_x \cdot b_y \cdot c_z) \pi^{1.5};$$

$$KG = \frac{2c^{1.5}}{d}$$

$$f_{Gol}(x,y,z,t) = KG \exp\left(-\left((x_0 + v(\tau-t))^2 k_x + y^2 k_y + z^2 k_z\right)\right)$$

■ R^2 für äquivalente Verteilung

$$f_{Gol}(x,y,z,t) = KG \exp\left(-\left(kR^2\right)\right)$$

Modification Phase 1 (without Reinforcement)

■ ÄWQ nach Goldak

$$f_{Gol}(x, y, z, t) = KG \exp\left(-\left(kR^2\right)\right)$$

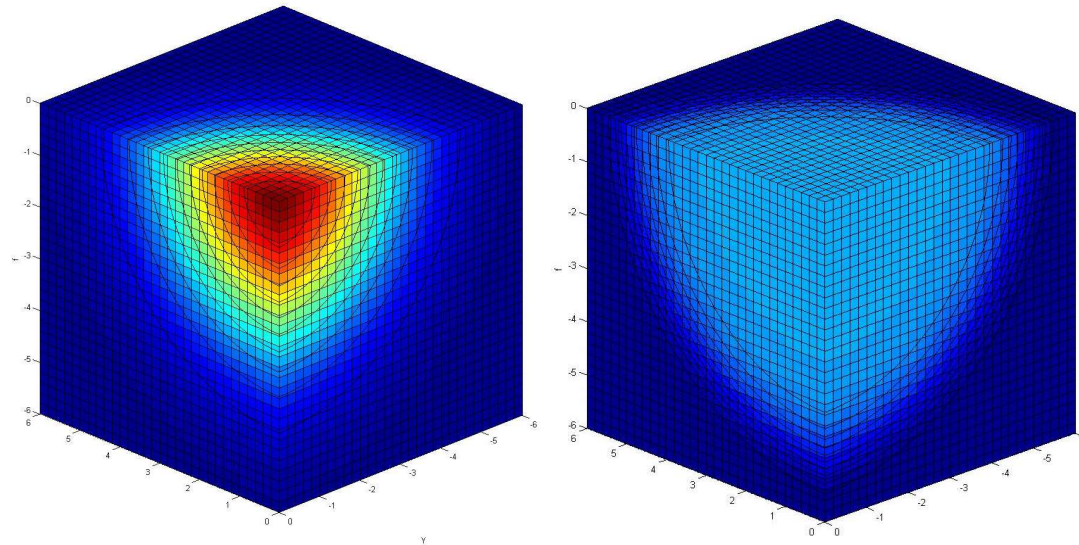
$$k_x = \frac{c}{a_x^2}; \quad k_y = \frac{c}{b_y^2}; \quad k_z = \frac{c}{c_z^2}; \quad d = (a_x \cdot b_y \cdot c_z) \pi^{1.5}; \quad c = 3; \quad KG = \frac{2c^{1.5}}{d}$$

■ modifizierte ÄWQ MR¹⁰

$$f_{MR10}(x, y, z, t) = KM \exp\left(-\left(kR^2\right)^5\right)$$

$$c = 2; \quad KM = \frac{2c^{1.5}}{d \cdot 0.6687}$$

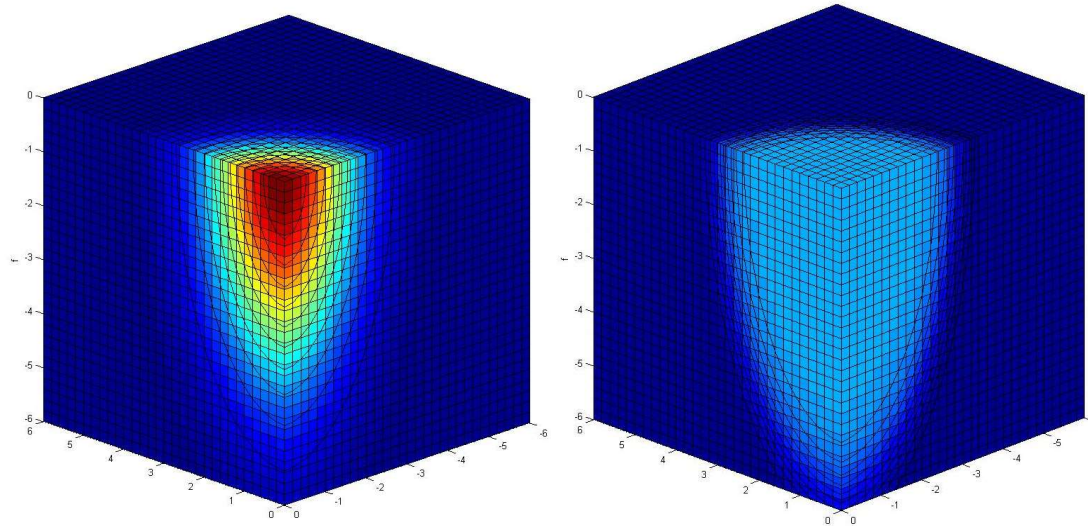
$$\left(-\left(kR^2\right)^5\right) = -k^5 R^{10}$$



$$f_{Gol}(x, y, z, t) = KG \exp\left(-\left(kR^2\right)\right) \quad f_{MR10}(x, y, z, t) = KM \exp\left(-\left(kR^2\right)^5\right)$$

$$r_x = r_y = r_z = 5; \quad c = 3; \quad k_x = \frac{c}{r_x^2}; \quad k_y = \frac{c}{r_y^2}; \quad k_z = \frac{c}{r_z^2};$$

$$d = (r_x \cdot r_y \cdot r_z)\pi^{1.5}; \quad KG = \frac{2c^{1.5}}{d}; \quad KM = \frac{2c^{1.5}}{d \cdot 0.6687};$$

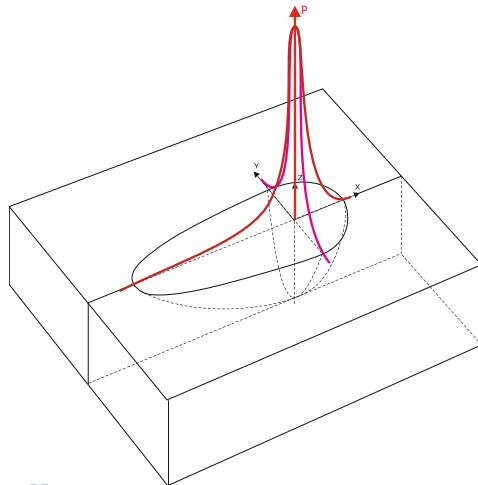


$$f_{Gol}(x, y, z, t) = KG \exp\left(-\left(kR^2\right)\right) \quad f_{MR10}(x, y, z, t) = KM \exp\left(-\left(kR^2\right)^5\right)$$

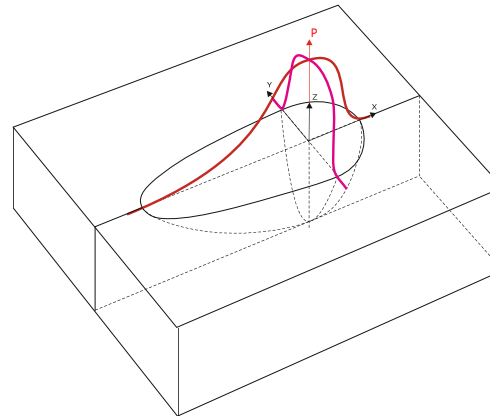
$$r_x = r_y = 3; r_z = 6; \quad c = 3; \quad k_x = \frac{c}{r_x^2}; k_y = \frac{c}{r_y^2}; k_z = \frac{c}{r_z^2};$$

$$d = (r_x \cdot r_y \cdot r_z) \pi^{1.5}; \quad KG = \frac{2c^{1.5}}{d}; \quad KM = \frac{2c^{1.5}}{d \cdot 0.6687};$$

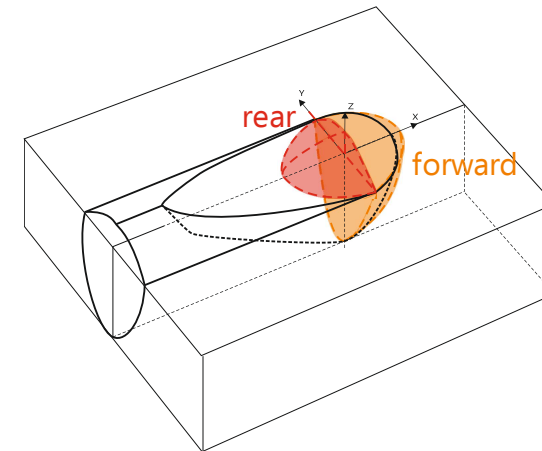
Modification Phase 2 (with Reinforcement)



ÄWQ nach Goldak



Phase 1

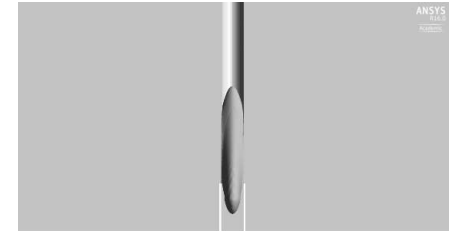
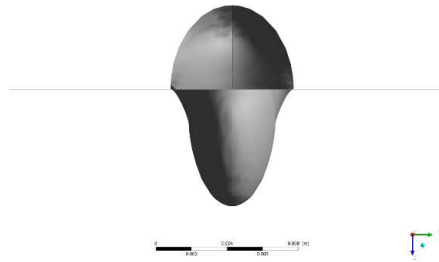


Phase 2

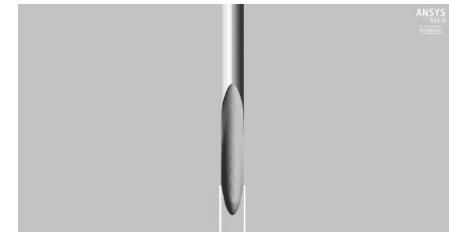
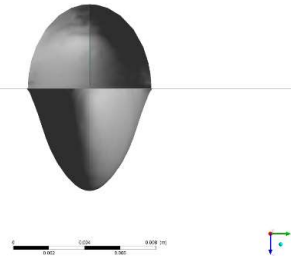
- Forward part → in Plate (if $(x_0 + v(\tau - t) < 0)$) ONLY
- Rear part → in Reinforcement (if $(x_0 + v(\tau - t) > 0)$) ONLY

475 A, 30 V, 80 cm/min

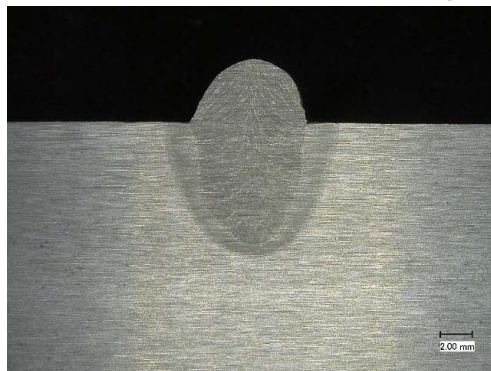
MR10



GoldakMR2



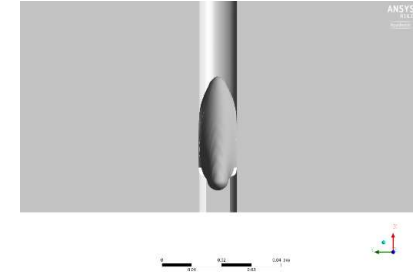
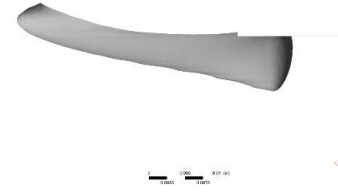
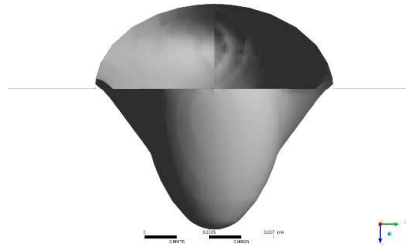
Exp.



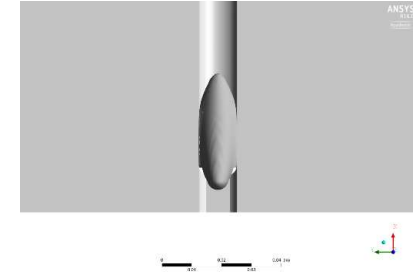
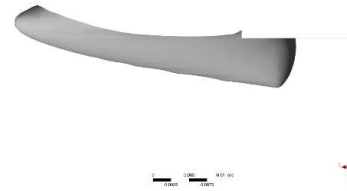
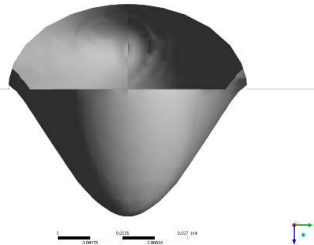
Liquidus-z (MÄWQ) [mm]: 8,01
Liquidus-z (Goldak) [mm]: 7,15
Liquidus-z (Exp.) [mm]: 8,13

475 A, 32 V, 40 cm/min

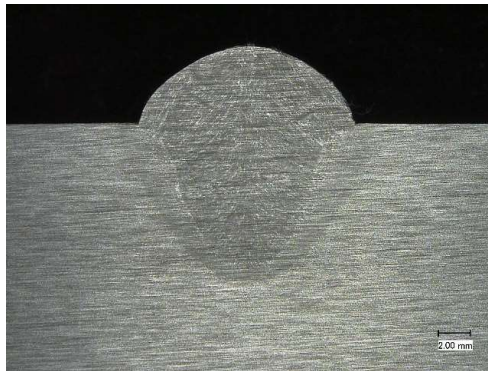
MR10



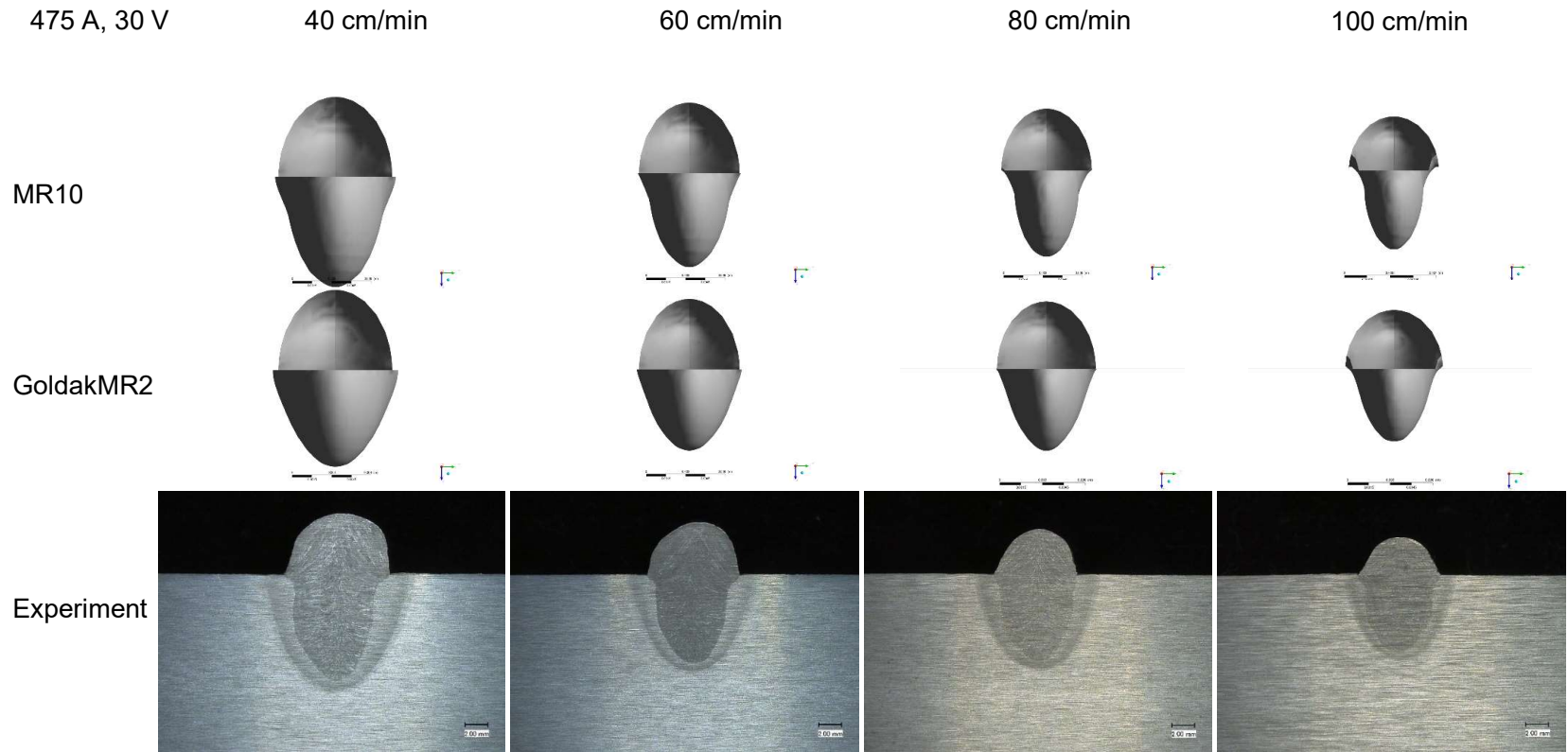
GoldakMR2



Exp.



Liquidus-z (MÄWQ) [mm]: 8,86
Liquidus-z (Goldak) [mm]: 8,37
Liquidus-z (Exp.) [mm]: 8,4



475 A; 30 V; 40, 60, 80, 100 cm/min

475 A, 32 V

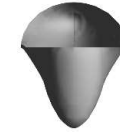
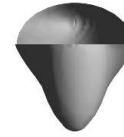
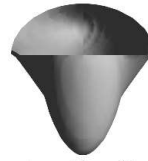
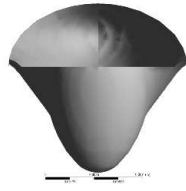
40 cm/min

60 cm/min

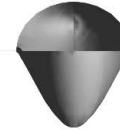
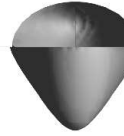
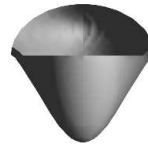
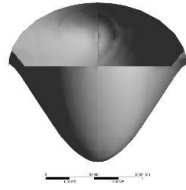
80 cm/min

100 cm/min

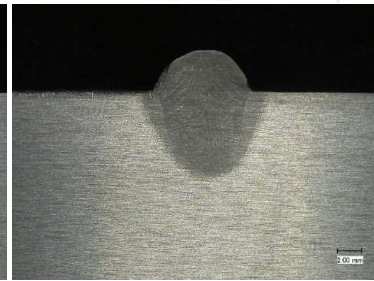
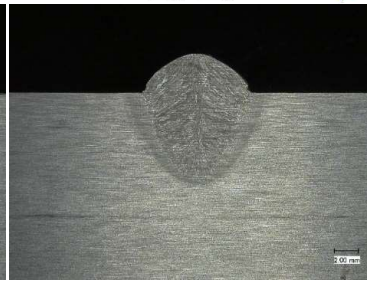
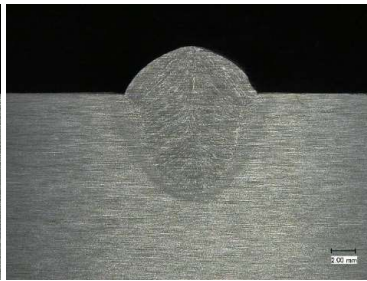
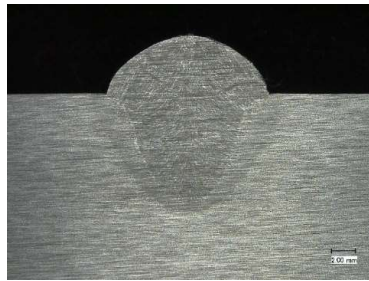
MR10



GoldakMR2



Experiment



475 A; 32 V; 40, 60, 80, 100 cm/min

475 A, 34 V

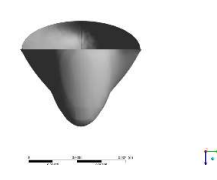
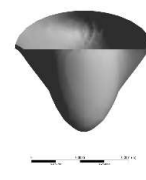
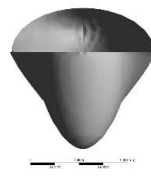
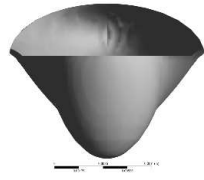
40 cm/min

60 cm/min

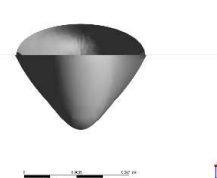
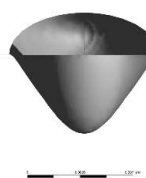
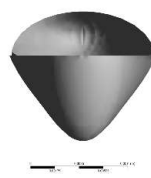
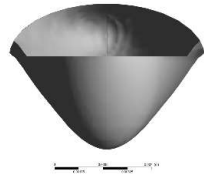
80 cm/min

100 cm/min

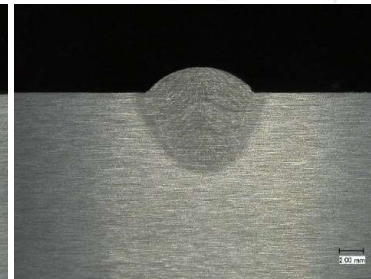
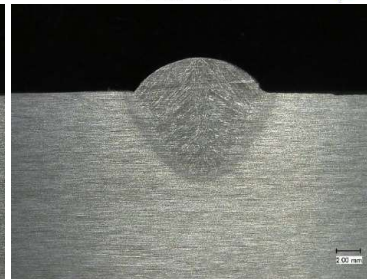
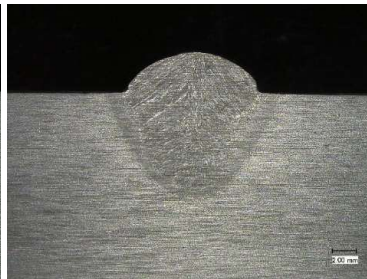
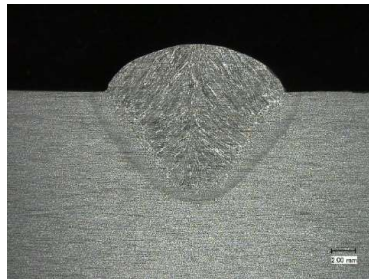
MR10



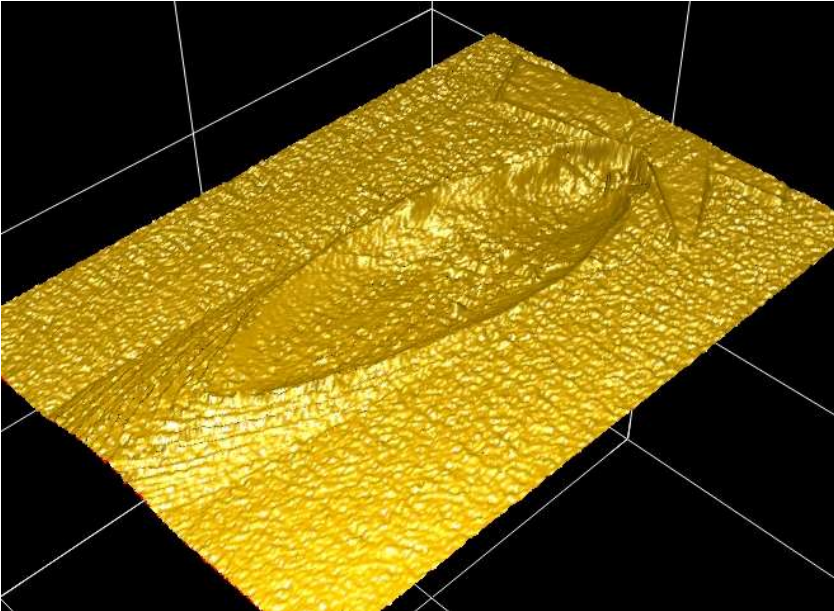
GoldakMR2



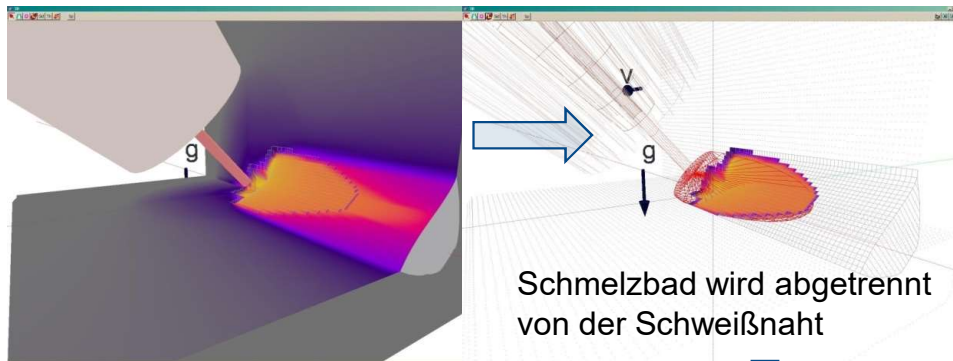
Experiment



475 A; 34 V; 40, 60, 80, 100 cm/min

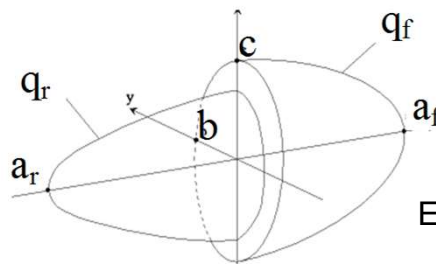


- Simulation der Schweißbadform
- Simulation der Wärmeströme
- Entwicklung von Algorithmen für die geometrische Beschreibung der Schmelzbadgrenze
- Entwicklung einer ÄWQ nach Goldak mit dem Prozesssimulationsprogramm *SimWeld*.

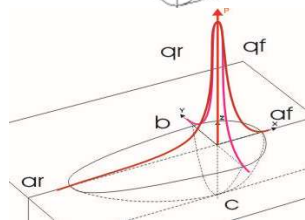


SimWeld Simulation

Schmelzbad wird abgetrennt von der Schweißnaht



Erzeugung von äquivalenten Ellipsoiden



Definition der Energieparameter
Definition der Verteilungsparameter
Erzeugung der Subroutine

Wärmequellen Funktion für DYNAWELD und SYSWELD sind automatisch mit SimWeld generiert.

```

22.14 Mathematische Funktionen - Editor
Datei Bearbeiten Format Ansicht ?
#OPERATOREN
#-----
#Subtrahieren und negatives Vorzeichen
-
#Addieren
+
#Multiplizieren
*
#Dividieren
/
#Rest einer nicht aufgehenden Division
%
#Bitweises Nicht. Nur bei Integer.
~
#Logisches Nicht. Nicht bei Stringoperationen.
!
#Bitorientiertes Und
&
#Bitorientiertes ausschließliches Oder
^
#Bitorientiertes inklusives Oder
|
#Arithmetischer Links- und Rechts-Shift. Nur für Integer.
<< >>
#Alle nachfolgenden Operatoren geben eine Boolesche 1
#zurück, wenn die Bedingung stimmt, ansonsten 0. Gilt für
#Strings, Integers und Kommazahlen.
#Weniger als
<
#größer als
>
#kleiner gleich
<=
<
38      XO = 0.0 ; [mm]
39      YO = 0.0 ; [mm]
40      ZO = 0.0 ; [mm]
41      VY = 5.00000 ; [mm/sec]
42      AY = 48.46824 ; [degree]
43      C
    
```

generated in SimWeld
2.5.8
10 13:35:33
ld simulation:
line, no reference line. It is
auss point treated and time

**DynaWELD
C Subroutine**

**SYSWELD
Fortran Subroutine**

Computation of the absorbed power



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Vielen Dank für Ihre Aufmerksamkeit!