# Modelling of Arc Welding Power Source

COMSOL CONFERENCE 2014 CURITIBA

TSCHOEPKE, EDUARDO SILVA[1],
MAZZAFERRO, JOSÉ ANTÔNIO ESMERIO[1],
PAZ, GUILHERME[1]

[1]UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL, PORTO ALEGRE, RS, BRASIL

# Overview

- Objectives
- Goldak's Model
- Experiment
- Model Definition
- Validation
- Conclusions

# Objectives

Modelling Arc Welding Heat Source to Predict Peak Temperatures and Cooling Rate

# Goldak's Model

## ➢ Heat Source - Characteristics:

- Double ellipsoid (half bottom) composed by two quarters of different ellipsoids

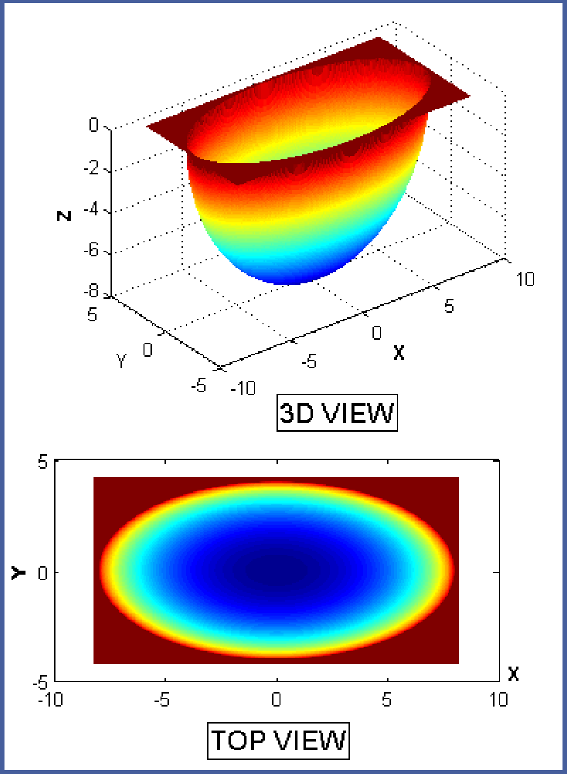
- Gaussian distribution of the power density inside the double ellipsoid

- Maximum value $q_0$ at the center of the double ellipsoid

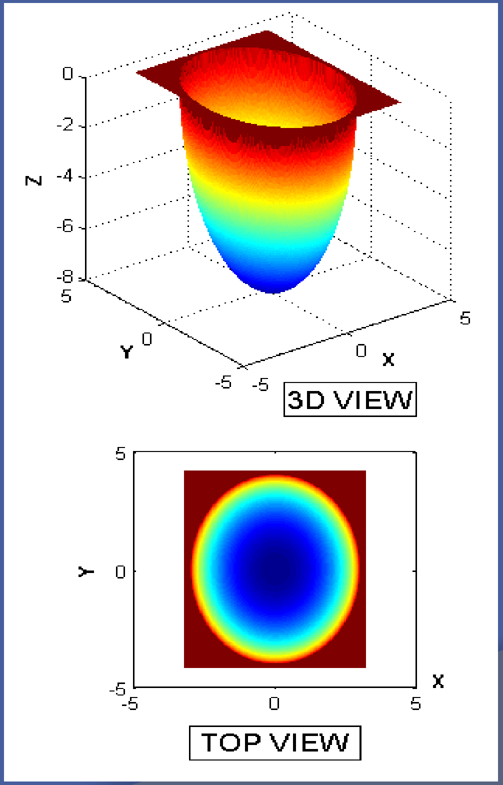
- Minimum value of 5 % of $q_0$ at the surface of the double ellipsoid

# Goldak's Model

- Heat Source - Geometry:



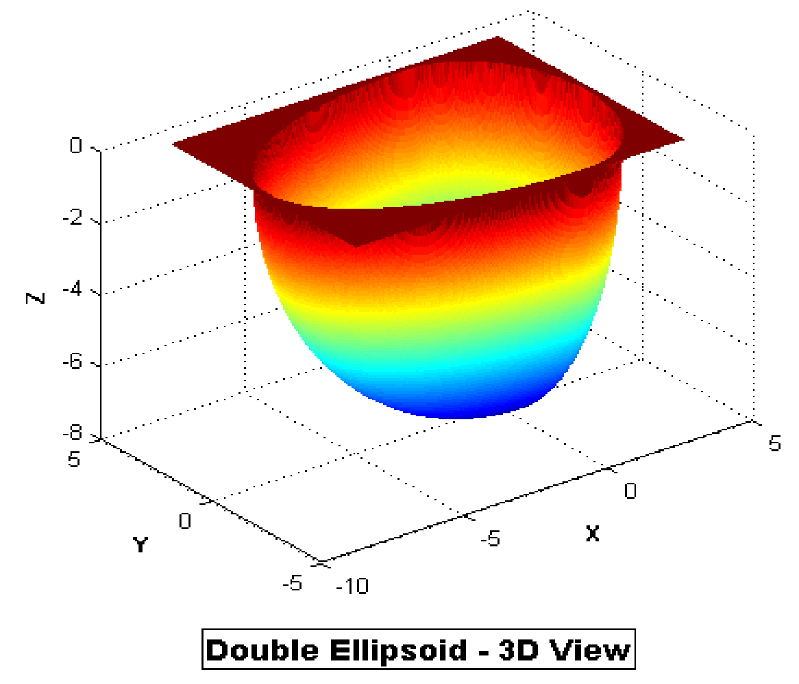

Ellipsoid A



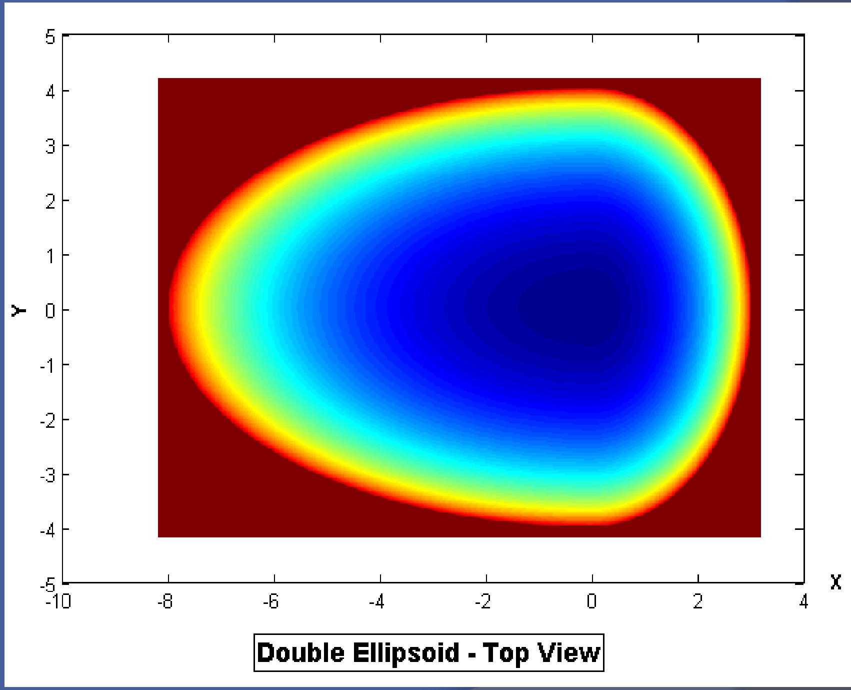

Ellipsoid B

# Goldak's Model

- Heat Source - Geometry:




Double Ellipsoid – 3D View




Double Ellipsoid – Top View

# Goldak's Model

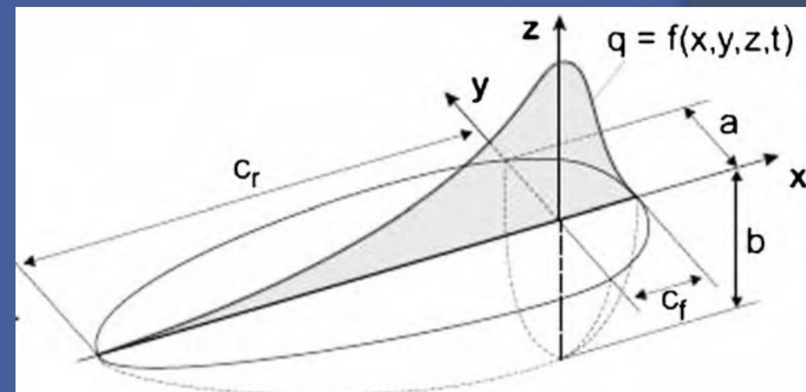
## ➢ Heat Source - Equations:

$$f_1(x,y,z,t) = \frac{6\sqrt{3} f_f Q}{abc_f\pi\sqrt{\pi}} e^{-3\left[\frac{(x-x_{00})^2}{{c_f}^2}+\frac{(y-y_0)^2}{a^2}+\frac{(z-z_0)^2}{b^2}\right]}$$

Power density distribution inside the Front quadrant

$$f_2(x,y,z,t) = \frac{6\sqrt{3} f_r Q}{abc_r\pi\sqrt{\pi}} e^{-3\left[\frac{(x-x_{00})^2}{{c_r}^2}+\frac{(y-y_0)^2}{a^2}+\frac{(z-z_0)^2}{b^2}\right]}$$

PPower density distribution inside the Rear quadrant




Power Density Distribution Inside the Double Ellipsoid

$$q(x,y,z,t) = \begin{cases} f_1(x,y,z,t) & \text{for } x >= x_{00} \\ f_2(x,y,z,t) & \text{for } x < x_{00} \end{cases}$$

Where Q is the power rate,

$(x_0, y_0, z_0)$ is the center point,

$x_{00} = x_0 + vt$ and *v=welding speed.*

$f_f$ and $f_r$ are coefficients to ensure continuity condition,

$f_f + f_r = 2$,

$f_1(x_{00}, y,z,t) = f_2(x_{00}, y,z,t) \Leftrightarrow f_f / c_f = f_r / c_r$

# Goldak's Model

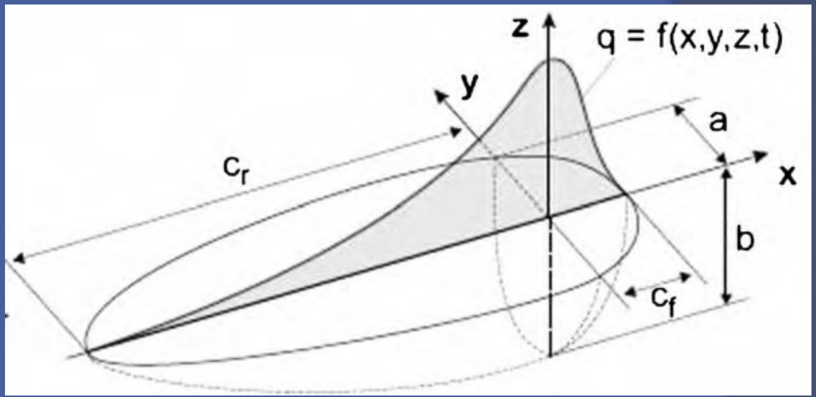
## Heat Source - Equations:

$$f_1(x,y,z,t) = q_0\, e^{-3\left[\frac{(x-x_{00})^2}{{c_f}^2}+\frac{(y-y_0)^2}{a^2}+\frac{(z-z_0)^2}{b^2}\right]}$$

Power density distribution inside the Front quadrant

$$f_2(x,y,z,t) = q_0 e^{-3\left[\frac{(x-x_{00})^2}{{c_r}^2}+\frac{(y-y_0)^2}{a^2}+\frac{(z-z_0)^2}{b^2}\right]}$$

PPower density distribution inside the Rear quadrant




Power Density Distribution Inside the Double Ellipsoid

$$q(x,y,z,t) = \begin{cases} f_1(x,y,z,t) & \text{for } x >= x_{00} \\ f_2(x,y,z,t) & \text{for } x < x_{00} \end{cases}$$

Where Q is the power rate,

$(x_0, y_0, z_0)$ is the center point,

$x_{00} = x_0 + vt$ and *v=welding speed.*

$f_f$ and $f_r$ are coefficients to ensure continuity condition

$f_1(x_{00}, y,z,t) = f_2(x_{00}, y,z,t) \Leftrightarrow f_f/c_f = f_r/c_r$

# Experiment

- **Process:**

  - Metal cored wire

  - C25 gas

  - Preheat Temperatures of -30 °C, 30 °C, 100 °C, 150 °C and 200 °C.

Robot and Power Source

- **Geometry:**

  API 5L X80 steel Plate of 32 mm thick with no chamfer, in bead on plate configuration.

Plate

# Experiment

- **Data Acquisition:**

  -Thermocouples:

  type K:

  - 1 positioned at the bottom of the plate.

  - 5 positioned 2 mm, 4 mm, 6 mm, 8 mm and 10 mm away from the bead.

  type S:

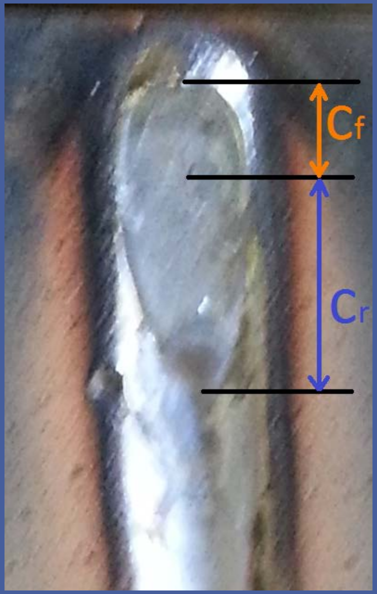
  - 1 plunged into the weld pool.

Thermocouples positioning

# Experiment

- Data Acquisition:

## Weld Pool Measures:



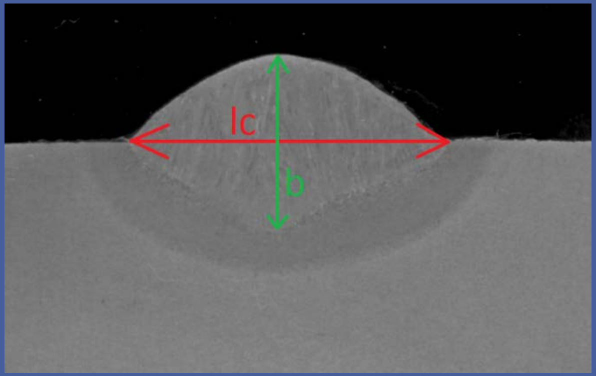

Weld Pool

front length:
$c_f$

rear length:
$c_r$

total length:
$c = c_f + c_r$

## Macrograph Measures:




Macrograph

width:
lc

penetration:
b

# Model Definition

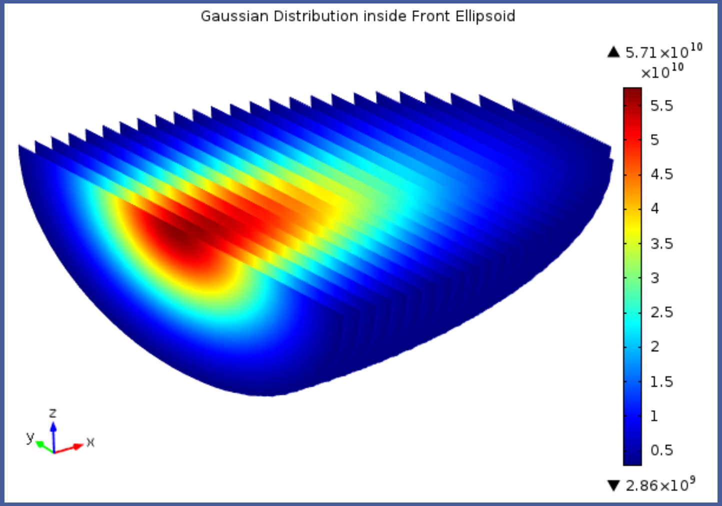
## Parameters

- Plate Geometry:
  - Length (l)
  - Width (w)
  - Thickness (th)
- Process:
  - Tension (U)
  - Current (I)
  - Thermal efficiency (n)
  - Welding speed (v)
  - Energy input rate (Q)
- Bead Geometry:
  - Penetration depth (p)
  - Bead width (bw)
  - Total length of the weld pool (c)
  - Front length of the weld pool (cf)
  - Rear length of the weld pool (cr)
- Source:
  - Front proportion coefficient (ff)
  - Rear proportion coefficient (fr)
  - Maximum power density (q0)
- Boundary conditions:
  - Pre-heat temperature (T0)
  - Ambient temperature (Tamb)
  - Convection coefficient (h)
- Initial conditions:
  - Source position (x0,y0,z0)
  - Temperature (T0)

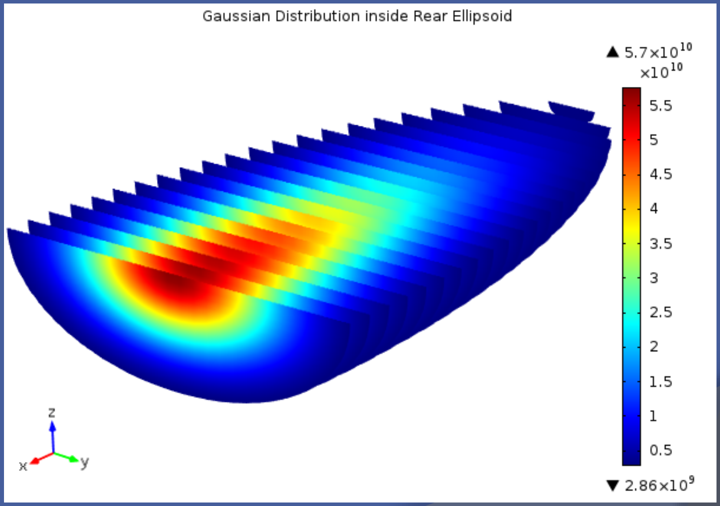
# Model Definition

## ➢ Functions

- Gaussian Distribution Inside of an Ellipsoid
  - expression: q0*(exp(-3*((A-A0)^2/CC^2+(B-B0)^2/a^2+(C-C0)^2/b^2)))




Front Part




Rear Part

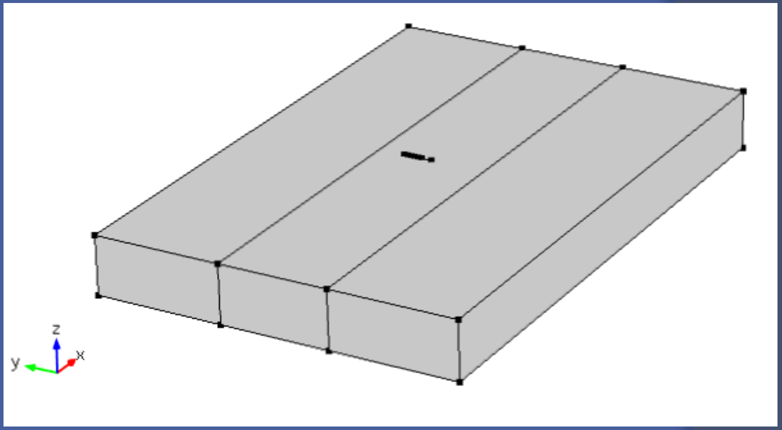
# Model Definition

- Variables
  - Sources center position
    - x00=x0+v*t
  - Source 1 (front part)
    - Q1=an1(x,x00,y,y0,z,z0,a,b,cf)*(x>=x00)
  - Source 2 (rear part)
    - Q2=an1(x,x00,y,y0,z,z0,a,b,cr)*(x<x00)

# Model Definition

- Geometry

**3D Component** with
-plate dimensions
-lines (to create different mesh regions)
-points at thermocouple position
(to improve accuracy at this points)




Geometric model of the plate

# Model Definition

## Heat Transfer in Solids Physic Module:

- Heat Source 1
  - General Source defined as (t<=wt)*Q1
    - Where (t<=wt) is the turn off condition

- Heat Source 2
  - General Source defined as (t<=wt)*Q2
    - Where (t<=wt) is the turn off condition

- Surface-to-Ambient Radiation

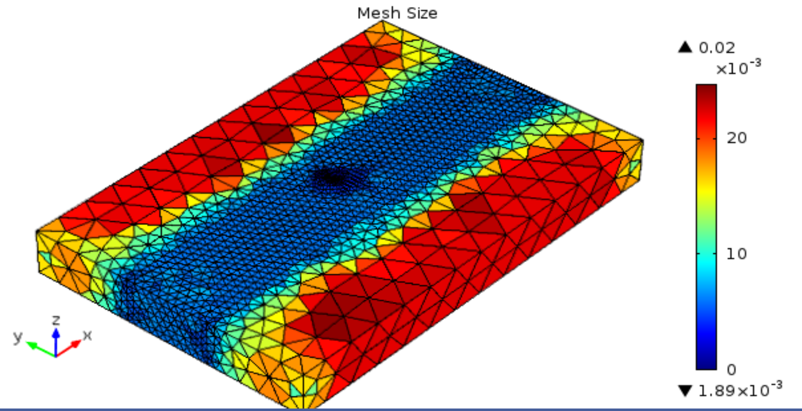
- Convective Heat Flux
  - User defined: Heat transfer coefficient = h

# Model Definition

- ## Mesh

### Surface Elements

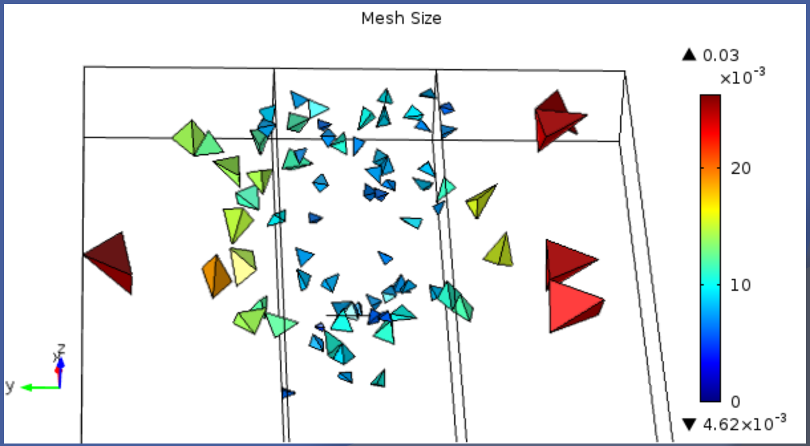
Triangles




Surface Elements Size

### Volume Elements

Tetrahedrons




Volume Elements Size

# Validation

- Peak Temperature

| Position | 2 mm away from bead | | | |
|---|---|---|---|---|
| Preheat Temperature | **30 °C** | **100 °C** | **150 °C** | **200 °C** |
| Experimental (°C ) | Failed | 1058 | Failed | 1196 |
| Numeric (°C ) | 1094 | 1054 | 1094 | 1128 |

| Position | 8 mm away from bead | | | |
|---|---|---|---|---|
| Preheat Temperature | **30 °C** | **100 °C** | **150 °C** | **200 °C** |
| Experimental (°C ) | Failed | Failed | 660 | 670 |
| Numeric (°C ) | 450 | 495 | 524 | 667 |

| Position | 4 mm away from bead | | | |
|---|---|---|---|---|
| Preheat Temperature | **30 °C** | **100 °C** | **150 °C** | **200 °C** |
| Experimental (°C ) | Failed | 889 | Failed | 798 |
| Numeric (°C ) | 759 | 773 | 810 | 842 |

| Position | 10 mm away from bead | | | |
|---|---|---|---|---|
| Preheat Temperature | **30 °C** | **100 °C** | **150 °C** | **200 °C** |
| Experimental (°C ) | Failed | 373 | Failed | 313 |
| Numeric (°C ) | 364 | 419 | 448 | 483 |

| Position | 6 mm away from bead | | | |
|---|---|---|---|---|
| Preheat Temperature | **30 °C** | **100 °C** | **150 °C** | **200 °C** |
| Experimental (°C ) | Failed | 660 | 743 | 670 |
| Numeric (°C ) | 575 | 604 | 633 | 667 |

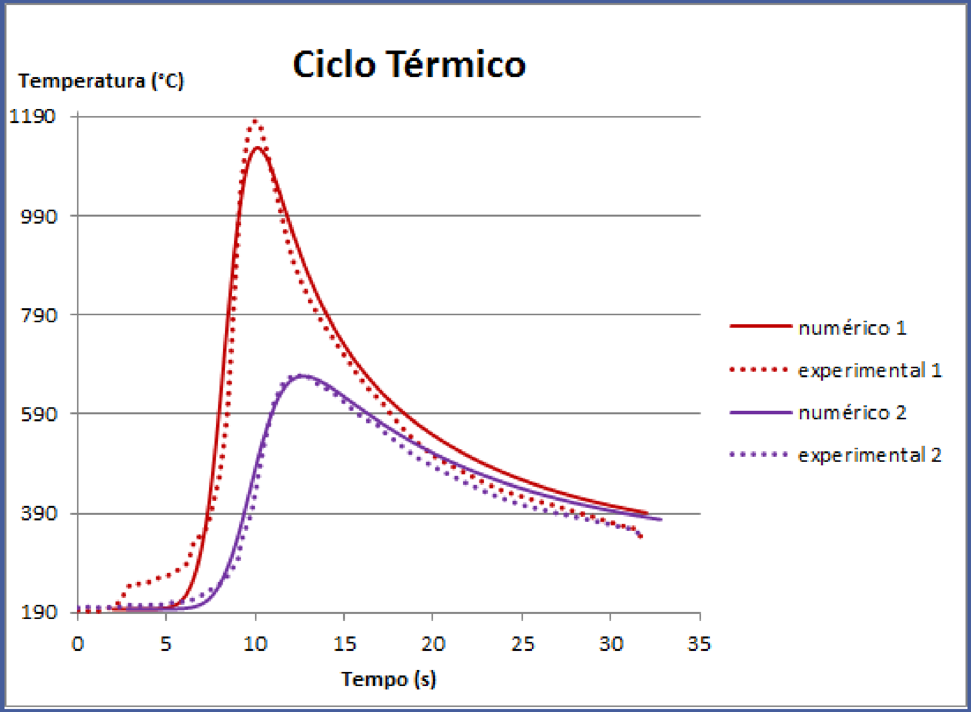
# Validation

- Cooling Time

| Cooling Time 800 °C to 500 °C (s) | | | | | |
|---|---|---|---|---|---|
| | -30 °C | 30 °C | 100 °C | 150 °C | 200 °C |
| Experimental | 4.47 | 5.55 | 6.83 | 7.55 | 10.50 |
| Numeric | 4.65 | 5.10 | 7.35 | 8.40 | 10.55 |

# Validation

- Thermal Cycle




Preheat of 200 °C

# Future Works

- Consider Phase Transformation
- Consider Material Deposition
- Predict the Microstructure
- Evaluate Distortion and Residual Stress

# Conclusions

Through this study it was possible to conclude that COMSOL Multiphysics provide sufficient conditions to simulate the electric arc welding process in order to obtain the cooling rate and peak temperatures.

# References


- 1. J. Goldak, A. Chakravarti and M. Bibby: A New Finite Element Model for Welding Heat Sources, Metallurgical Transactions B, vol. 15b, 1984.
- 2. Machado, Ivan Guerra: Condução do Calor na Soldagem: Fundamentos e Aplicações, Porto Alegre, RS, Brazil, 2000.
- 3. N. T. Nguyen, Y. W. Mai, S. Simpson and A. Ohta: Analytical Approximate Solution for Double Ellipsoidal Heat Source in Finite Thick Plate, Welding Journal, march 2004.
- 4. H. M. Aarbogh, M. Hamide, H. G. Fjaer, A. Mo and M. Bellet: Experimental validation of finite element codes for welding deformations, Journal of Materials Processing Technology 210 (2010).
- 5. A. Anca, A. Cardona, J. Risso and V. D. Fachinotti: Finite element modeling of welding processes, Applied Mathematical Modelling 35 (2011).

Thank you for your attention!

Any question?

Contact: 196575@ufrgs.br

- Acknowledgement – To FAPERGS – Fundação de Amparo à Pesquisa do Rio Grande do Sul – for providing financial support that allowed COMSOL license acquisition