# Gas radiation model for reheating furnaces

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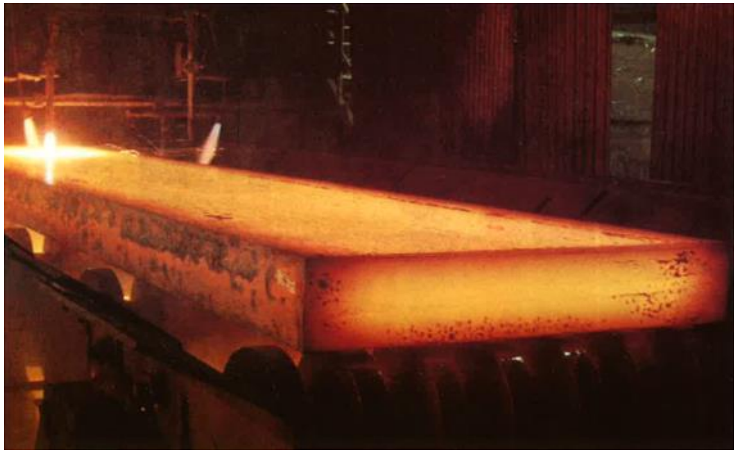
# Background

- Modelling of gas radiation is needed for calculations of stock temperatures in furnace simulations and in process control when there is infrared radiative gases
- Swerea MEFOS, together with IFE (Norway) and Jernkontoret, have developed the software STEELTEMP® that e.g. calculates heat transfer from gas and wall to stock in reheating furnaces
- The furnace control system FOCS, delivered by PREVAS, has the same calculation models for e.g. heat transfer

# STEELTEMP® 2D

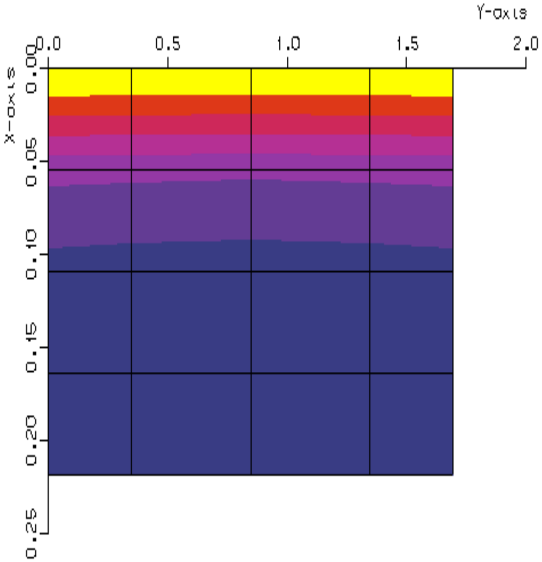
- STEELTEMP® 2D is a software using mathematical models for heat transfer analysis and temperature calculations for a number of different processes:
  - Casting
  - Cooling
  - Heating
  - Flat rolling
  - Open-die forging
  - Quenching



- STEELTEMP® 2D increases the control of the slab temperature and the process, which give a more efficient production with a higher product quality.

# STEELTEMP® 2D

- Temperatures and heat densities are calculated in stocks with rectangular or circular cross sections
- Composite structures can be analysed and temperature gradients in the stocks can be minimized




# Important parameters in gas radiation modelling

- $\varepsilon_g$ = Emissivity of furnace gases
  - Near zero for protective gases, e.g. $N_2$ and $H_2$
  - Very important for oxyfuel fired furnaces with high levels of water vapour and carbon dioxide
- $A_g$ = Absorptivity
  - Near zero for protective gases, e.g. $N_2$ and $H_2$
  - Very important for oxyfuel fired furnaces with high levels of water vapour and carbon dioxide
  - Function of surface temperature in addition to the same parameters as for gas emissivity
- $\tau_g$ = Transmissivity
  - $\boldsymbol{\tau_g = 1 - A_g}$
  - Near 1 for protective gases

# Model for radiation heat exchange in a furnace room

The radiation heat exchange between the flue gas ($CO_2$, $H_2O$ and $SO_2$), the walls, roof and the stock, respectively is described by the model

$$\varphi_s = \frac{\sigma\varepsilon_s}{1-(1-\varepsilon_s)(1-A_{gs})}(\varepsilon_g\Theta_g^4 - A_{gs}\Theta_s^4) + \sigma\varepsilon_{sw}(\Theta_w^4 - \Theta_s^4) \stackrel{\Delta}{=} \varphi_{g,s} + \varphi_{w,s}$$

where

$\varepsilon_s$ = emissivity of stock [-]

$\varepsilon_g$ = emissivity of gas [-]

$\varepsilon_{sw}$ = radiation heat exchange factor between walls, roof and stock, respectively [-]

$\Theta_s$ = stock temperature [K]

$\Theta_g$ = gas temperature [K]

$\Theta_w$ = wall temperature [K]

The absorptivities of $CO_2$ and $H_2O$ gas to radiation are given by

$$A_{gs} = \left( \frac{\Theta_g}{\Theta_s} \right)^{0.65} * \varepsilon_{g_{CO2}} (\Theta_s, s * p_{CO2} \frac{\Theta_s}{\Theta_g})$$

and

$$A_{gs} = \left( \frac{\Theta_g}{\Theta_s} \right)^{0.45} * \varepsilon_{g_{H2O}} (\Theta_s, s * p_{H2O} \frac{\Theta_s}{\Theta_g})$$

where

s = thickness of the gas layer [-]

$p_{xi}$ = partial pressure of the flue gas component $x_i$ [atm]

For calculation of the gas emissivity, as a function of the gas temperature, the partial pressure of $CO_2$, $H_2O$ and $SO_2$ and the gas layer thickness, analytical expressions derived by K. Schack are used. These expressions are based on the accurate gas radiation measurements made by Hottel and Egbert in 1942.

The radiation exchange factor between the walls, roof and the stock is given by

$$\varepsilon_{sw} = \varepsilon_s \varepsilon_w \tau_g \beta_{sw} + \Delta\varepsilon_{sw}, \qquad \beta_{sw} = \sum_{k=1}^{N} \frac{1}{2}(\sin\beta_k^{'} - \sin\beta_k)$$

where

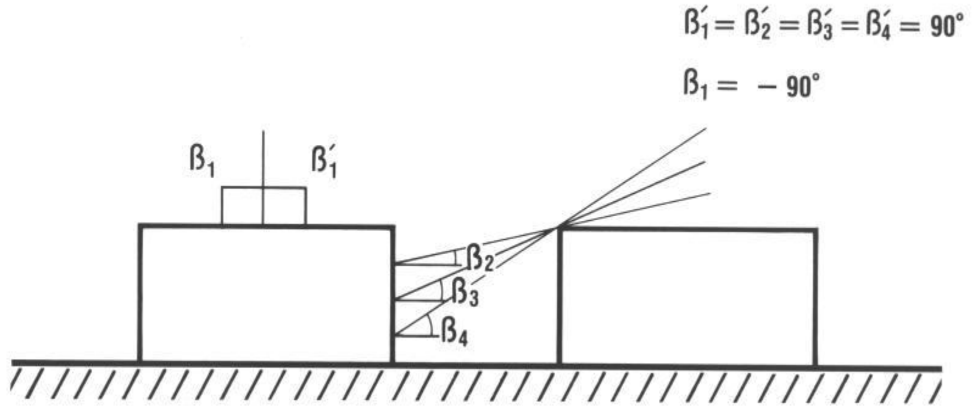
$\varepsilon_w$ = emissivity of wall [-]

$\tau_g$ = transmissivity of gas

$\beta_{sw}$ = view factor from the walls and roof to the stock [-]

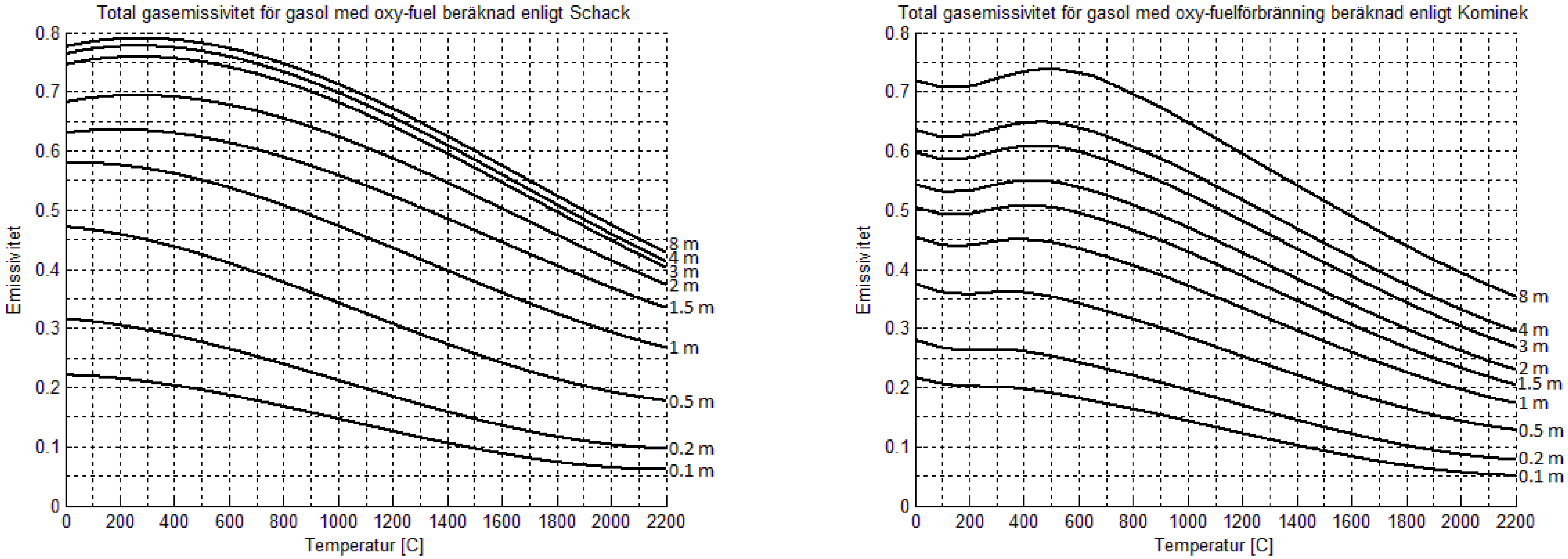
$\Delta\varepsilon_{sw}$ = correction factor for flame radiation [-]

In the program the view factors and the gas layer thicknesses are calculated automatically from geometrical data describing the location of the stock with neighbours in the furnace. The users can also give their own values of the gas layer thicknesses.



# Total gas emissivity – oxyfuel fired propane

**Adaptions of Schack vs Kominek from Hottel's data**




The graphs show emissivity for different gas layer thickness.

Gas layer thickness = 1.76 x distance (between infinite parallel surfaces)

# Gas radiation modelling in the industry

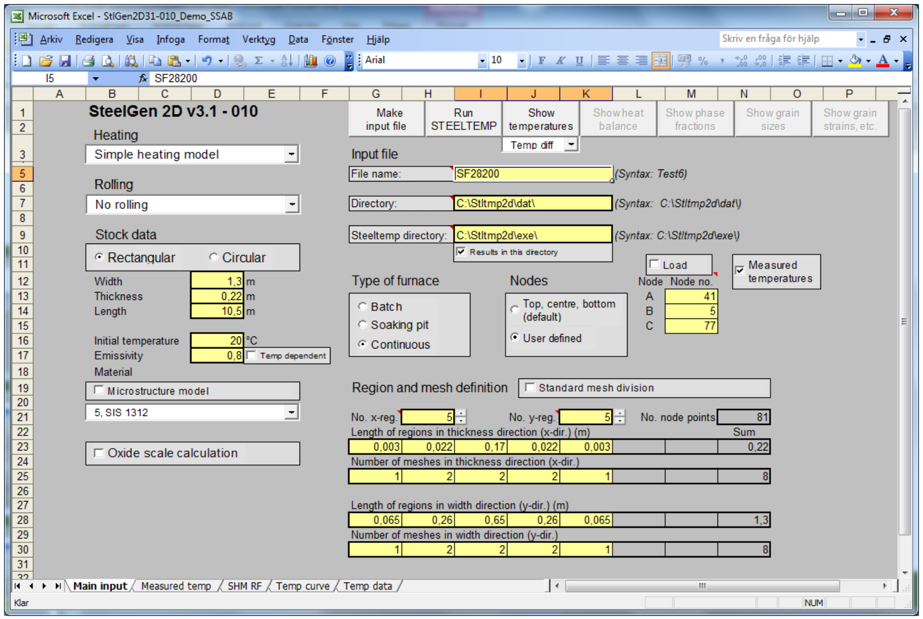
- Continuous heat treatment furnaces
  - e.g. Outokumpu KBR with oxyfuel firing needs accurate gas radiation modelling

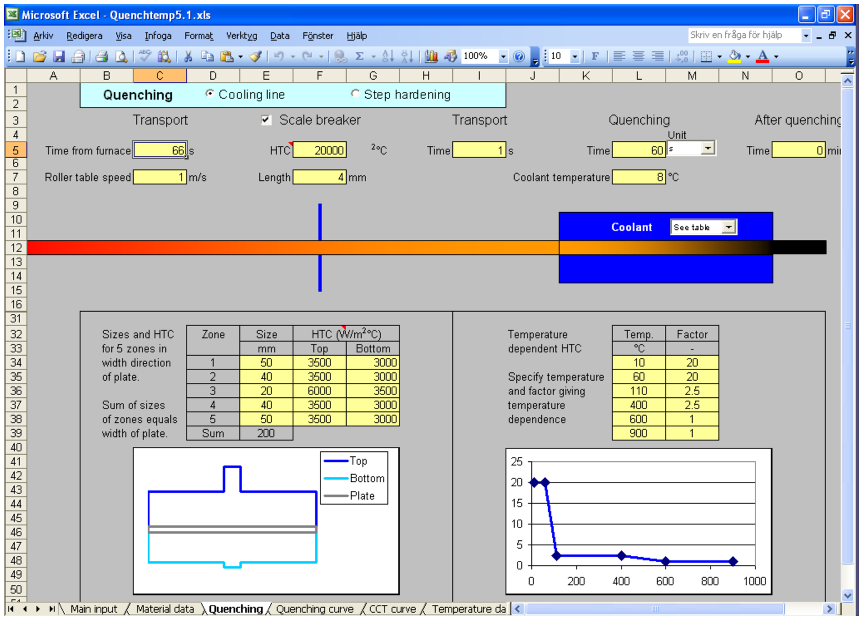

- Small batch furnaces with protective gas – heat transfer modelling of heating and cooling but no gas radiation modelling

- STEELTEMP heat transfer modelling can be used in many different furnaces

# User-Friendly Excel Interfaces for SteelTemp

- SteelGen
- QuenchTemp




- New on-line version of STEELTEMP is under development

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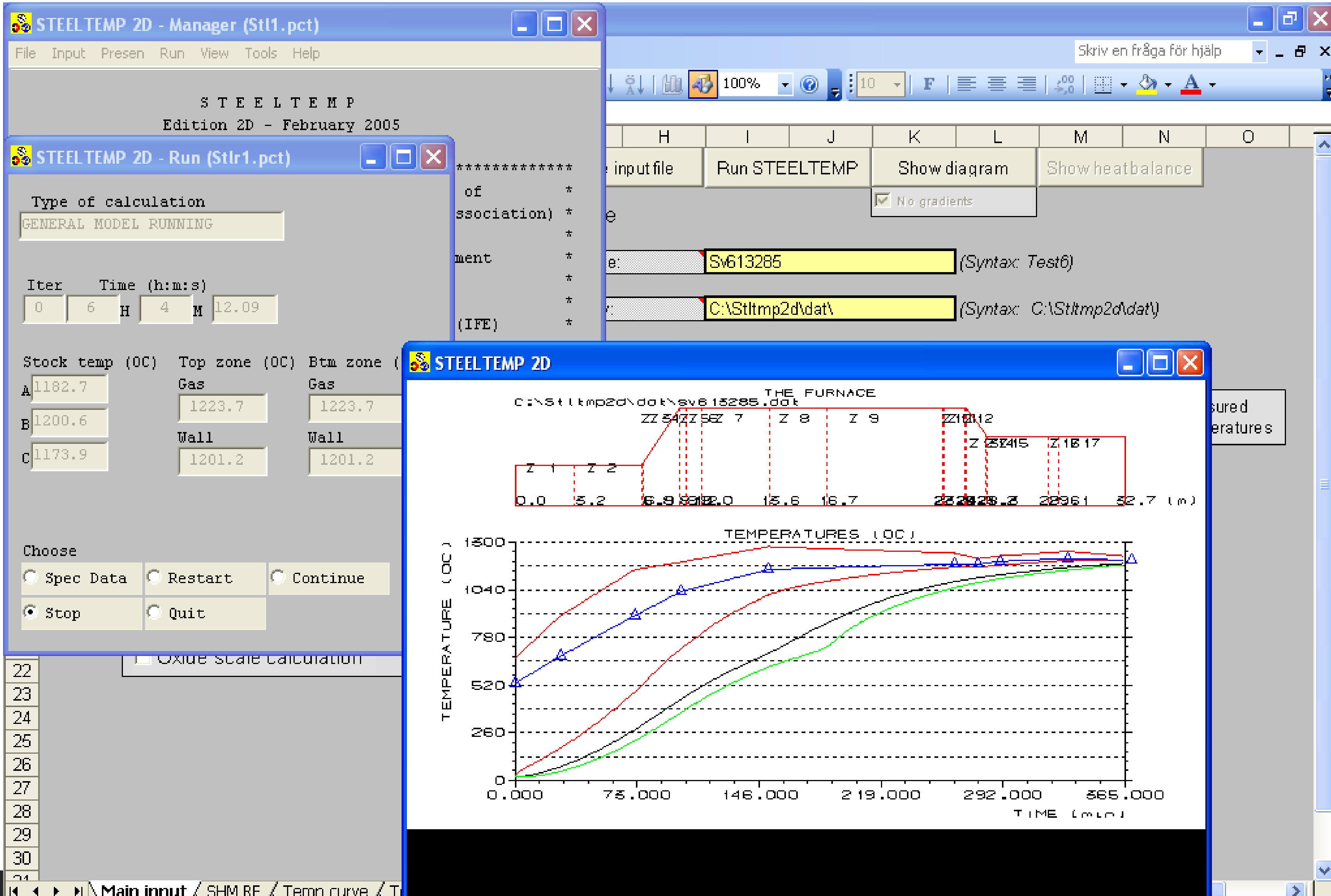
STEELTEMP 2D - Manager (Stl1.pct)
File Input Presen Run View Tools Help
S T E E L T E M P
Edition 2D - February 2005
STEELTEMP 2D - Run (Stlr1.pct)
Type of calculation
GENERAL MODEL RUNNING
Iter Time (h:m:s)
0 6 H 4 M 12.09
Stock temp (OC) Top zone (OC) Btm zone (
Gas Gas
A 1182.7 1223.7 1223.7
B 1200.6
Wall Wall
C 1173.9 1201.2 1201.2
Choose
Spec Data
Restart
Continue
Stop
Quit
Skriv en fråga för hjälp
100%
H I J K L M N O
input file
Run STEELTEMP
Show diagram
Show heatbalance
No gradients
Sv613285
(Syntax: Test6)
C:\Stltmp2d\dat\
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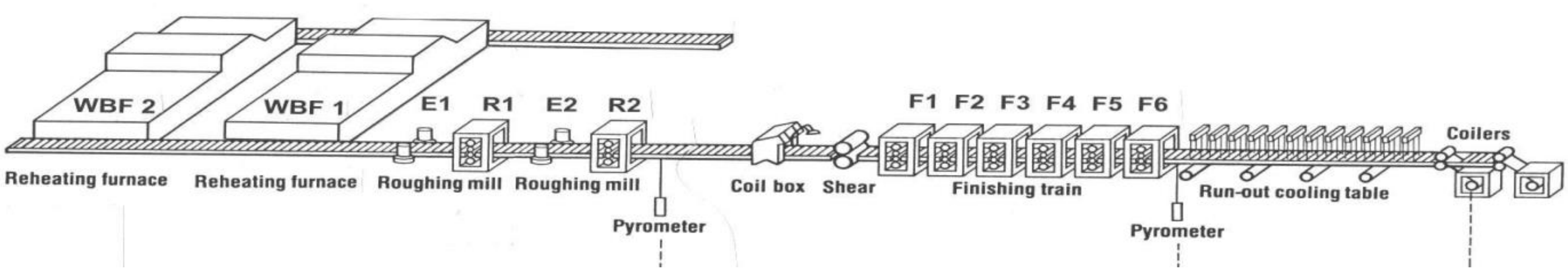
STEELTEMP 2D
THE FURNACE
C:\Stltmp2d\dat\sv613285.dat
TEMPERATURES (OC)
TEMPERATURE (OC)
1300
1040
780
520
260
0
0.000
73.000
146.000
219.000
292.000
365.000
TIME (min)
Main input
SHM RF
Temp curve

# Flue gas calculation with oxygen enrichment

- Flue gas flow is calculated in each furnace zone using:
  - Chemical analysis of fuel
  - Fuel flow of up to four different fuels
  - Air flow
  - Oxygen
- Calculations normally start in the soaking zone but arbitrary flue gas flow is possible
- Flue gas composition is calculated for each zone

# Microstructure model as DLL in STEELTEMP® 2D

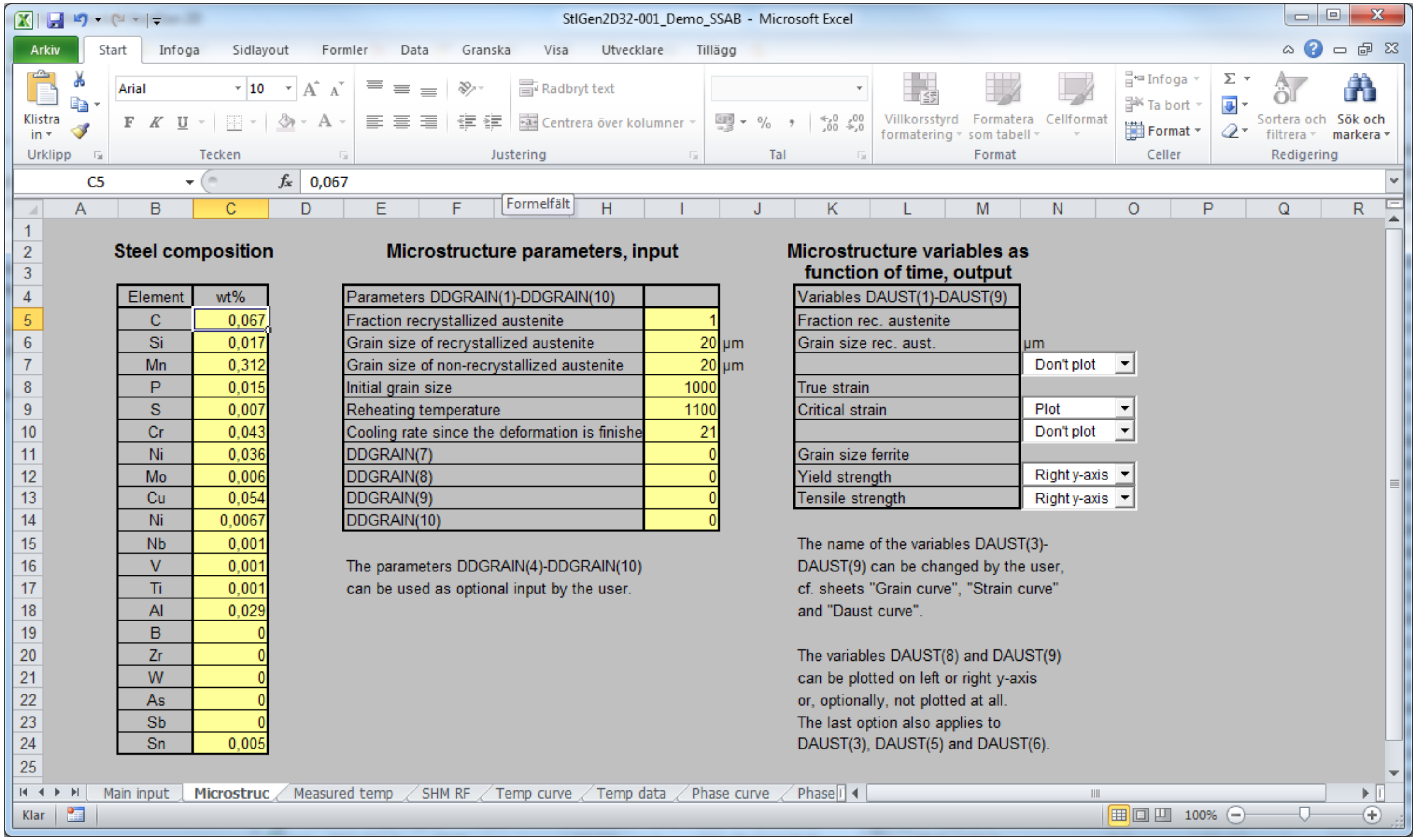
- User-defined microstructure model can be used in STEELTEMP® 2D
- Process and microstructure data can be defined and results plotted in STEELGEN 2D



# Microstructure data in STEELTEMP® 2D

- General microstructure data:
  - Steel composition in weight per cent
  - Fraction of microstructure constituents (austenite, ferrite, perlite, cementite, bainite, martensite)
  - Fraction recrystallized austenite, grain sizes of recrystallized and non-recrystallized austenite
  - Grain deformation parameters
  - Nucleation densities
- The variables can be plotted in STEELGEN 2D
- User-defined variables

# Sheet for microstructure data



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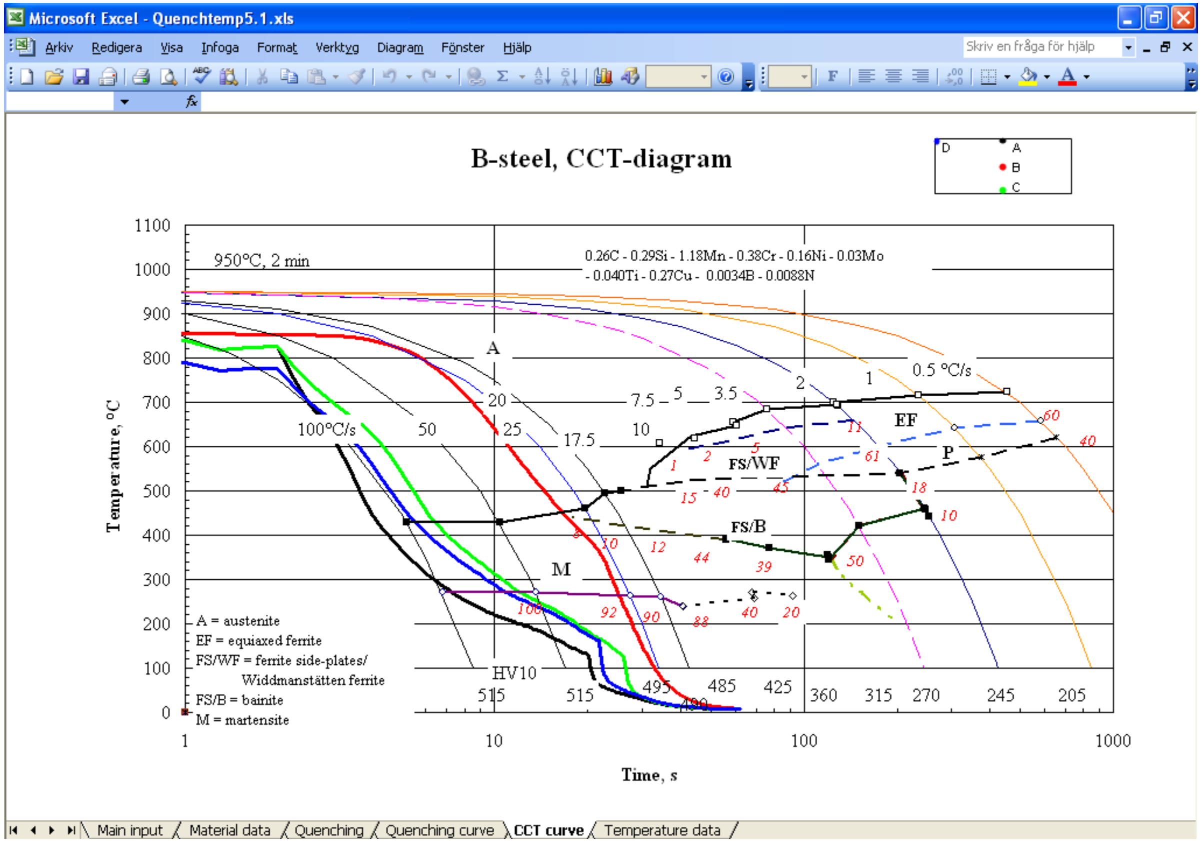
# Cooling Cycles in STEELTEMP® using Quenchtemp



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# Summary of calculations in STEELTEMP®

- Temperature calculations of heat transfer with gas radiation and wall radiation in arbitrary flue gas atmosphere

- Calculations of microstructure after heat treatment for processes including heating and cooling

- STEELTEMP calculations can be applied for online process control in FOCS in cooperation with PREVAS

**Thank you for your attention!**

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