SC-Consultants

Based on a 30-year experience, SC-Consultants is your partner in manufacturing processes optimization by providing numerical engineering applied solutions

Control the process to control the Product
The SC-Consultants company

30 years of experience in consulting actions and software solutions provider for manufacturing processes:

- **Foundry, Casting, Heating & Cooling, Solidification**
  - Aeronautic / Automotive / Nuclear / Hydraulic
- **Extrusion**
  - Agro & Pet Food / Plasturgy
- **Mixing**
  - advanced materials, Pharma
The SC-Consultants company

A French company

- Based in Saint Etienne (France) and a subsidiary in Montreal (Canada)
- Specialized in the **industrial processes optimization**
- **Software edition**
- **Services and consulting**
- 10 employees
- **Worldwide experience** and implementation
  - R&D facilities
  - Technical partnerships
  - Commercial partnerships
The SC-Consultants company

Strategic Initiatives
- Scientific community
  - For project development
  - For collaborative R&D

Services
- Dissemination of R&D outcomes
  - Consultancy
  - Technical assistance on process simulation
  - Training

Software solution provider
- Process specific software Edition
- Application specific software Development
The SC-Consultants R&D background

Partnerships with specialized laboratories

- **CEMEF** From Mines ParisTech
  Material behaviour, numerical developments

- **INRA**
  National Research Center on Agro Food
  Material characterization

- **Institut Jean Lamour**
  From Ecole des Mines de Nancy
  Metalworking industries

Techno partners

- Aimplas, Fraunhofer, Univ Bonn, Univ Cleveland, Univ Lowell, ...
Solid® software

Based on a 2D model, the Solid software is dedicated to casting/ingots casting simulation

Control the process to control the Product
Introduction

- Applications
  - For simplified geometries (2D)
  - Continuous casting
  - Ingots casting
  - Fixed mesh (no distortions)
Collaborative model

- **Scientific background**
  - Research development performed in close collaboration of Pr Herve Combeau from IJL - Nancy Lorraine University
    - List of publication available
  - Continuous development since 1993
  - Industrial consortium (national and private funds)

- **Software**
  - Research industrialization performed by SCC
  - Solid Users's Club
Overview

Features

- 2D Model
- Process Control
- Easy set up
- Fast computation

Benefits

- For any applications
- Indeep analysis
- Fast computations
- Fast ROI

Simulation software for solidification

For all Casting issues

Screening functioning window

Knowledge capitalization
Solid focus

- Solid: simulation of metallic alloys solidification
State diagram

- At the equilibrium state

Temperature decrease
The solid state - Typical structure

- Composed by a set of "grains"

Industrial scale segregations (macro, meso and micro)

Solidification local time, shrinkage, porosity, grains morphology
Macroscopic view

Thermal convection

Solute convection

Case of a lighter solute as the environment liquid

Case of heavier solute as the environment liquid
Microscopic - Simplified model for solidification

- **Simplified growth:**
  - **Perfect diffusion**
    \[ X_l = \frac{X_0}{f_l + (1 - f_l)k} \]
  - **No diffusion**
    \[ X_l = X_0 \cdot f_l^{k-1} \]
The different phenomena in solidification

- **Thermal**
  - Process parameters and alloys

- **CFD**
  - Thermo-Solute convection
    - + Solid motion

- **Segregation**
  - + Growth
  - Grains growth
    - + Microsegregation
Solid - 4 levels of modeling

- Thermal
  - Solidification front, Temperature

- Thermal + Fluid Mechanics + segregations (weak coupling) - No solid motion
  - Solidification front, Temperature
  - Velocity, pressure
  - Local compositions

- Thermal + Fluid Mechanics + segregations (strong coupling) - No solid motion
  - Solidification front, Temperature, velocity, pressure
  - Local composition

- Thermal + Fluid Mechanics + segregations (strong coupling) + solid motion + ECT (in option)
  - Solidification front, temperature, velocity, pressure
  - Local composition
  - Structures
Computations

- 2D resolution
- Finite volume
- Fluid mechanics: simplex method
- Growth: from simple to sophisticated scheme (dendritic, ....)
In Practice - 1

Configuration
- Geometry definition
- Setting of the appropriate materials and BC (RDB)
- Setting of the mesh (FV)

Data file construction by modules
- Files (non homogeneous initialisation, filling, …)
- Computation options, model selection
- Thermo-physical and metallurgical properties of the alloy
- Thermo-physical properties of the molding elements
- Quantification of boundary conditions

Computation setting up
- According to the model level: tens of minutes to …

Results analysis
- Isovalues maps, curves, … with Paraview software
In Practice - 2
Configuration and data file: an integrated framework on windows system

Solver: on demand on windows or Linux system /Paraview for post-process
Configuration: geometry, materials and BC
Configuration: mesh definition
Control file construction: **integrated**

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**Module Alliage**

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<tr>
<th>Parameter</th>
<th>Value</th>
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<td>stoke</td>
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<td>coeff</td>
<td>coefficient de partage de l’élément</td>
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</table>

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**Module Moutemement_grains**

- stockage de la segregation de l’élément
- composition de l’élément
- coefficient de partage de l’élément
- racine de liquide de l’élément

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**Module Materiau**

- Module Condition
- Module Developpeur
- Module Romplissage
- Module Particules
- Module Germination_Croissance
- Module Porosite
Control file construction: integrated
Taking into account filling: a simplified approach

Initialization with an empty mold

At the end of the filling

Ref: 3t3 ingot - Aubert & Duval
Taking into account filling: a simplified approach with a list of available results

Localization of secondary shrinkage and map of C segregations

Localization of primary shrinkage and Niyama criterium

Ref: 3t3 ingot - Aubert & Duval
Taking into account filling: a global analysis
Zoom on the filling stage

Evolution of volumes

Ref: 3t3 ingot - Aubert & Duval
Initialization with heterogeneous data: continuous simulation with unmoulding option

End of moulding stage (13h)  Instantaneous unmoulding  Thermal simulation (30mn)

Evolution of thermal flux (alloy)

Ref: 3t3 ingot - Aubert & Duval
Applications of Solid® software
Simulation application: Prediction in a 65 ton steel ingot (ArcelorMittal Industeel, France)

Development of macrosegregation and macrostructure

Flow through the columnar zone

Nucleation and fragmentation => CET

Grain growth

Morphology development

Solid-liquid interaction

Sedimentation and packing

Macrosegregation prediction in a 65 ton steel ingot - Combeau et all - ICRF, 2012
Industrial conditions - 65 ton ingot
(ArcelorMittal Industeel, Le Creusot)

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<tr>
<th>Element</th>
<th>Composition</th>
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<td>C</td>
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<tr>
<td>S</td>
<td>0.007%</td>
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<tr>
<td>P</td>
<td>0.008%</td>
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<tr>
<td>Si</td>
<td>0.18%</td>
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<tr>
<td>Mn</td>
<td>0.25%</td>
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<tr>
<td>Ni</td>
<td>1.14%</td>
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<tr>
<td>Cr</td>
<td>1.6%</td>
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<tr>
<td>Mo</td>
<td>0.19%</td>
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Thermosensors measurements in the mold

- Exothermic powder
- Hot top
- Cast iron molds
- Cast iron plate
- Sulfur print
- Macrostructure & macrosegregation

Macrosegregation

Thermosensors

Exothermic powder

Sulfur print

Macrostructure & macrosegregation
Simulation conditions in Solid - 65 ton ingot

Boundary conditions validated according to measurements in the mold

Comparison between 2 levels of modeling: fixed solid and grain motion
Global analysis: temperature evolution
Global analysis: local solidification time, liq fraction evolution after 8h30
Macrosegregations predictions - 65 ton ingot

Fixed solid

Moving grains

Centerline segregation
Macrosegregations predictions - 65 ton ingot (ArcelorMittal Industeel, Le Creusot)

Fixed solid
Moving grains
Centerline segregation
Macrosegregations predictions - 65 ton ingot (ArcelorMittal Industeel, Le Creusot)

Fixed solid

Moving grains

Centerline segregation
Understanding the macrosegregations creation - 65 ton ingot - Fixed solid

1h 30min
3h 45min
8h 10min
20h
Understanding the macrosegregations creation - 65 ton ingot - Fixed solid
Understanding the macrosegregations creation - 65 ton ingot - Fixed solid
Understanding the macrosegregations creation - 65 ton ingot - Moving grains

Grain density [m$^{-3}$]
Understanding the macrosegregations creation - 65 ton ingot - Moving grains

1h 15min 2h 40min 3h 45min 20h
Understanding the macrosegregations creation - 65 ton ingot - Moving grains

- T [°C]
- ΔC/C
- Grain density

1h 15min
2h 40min
3h 45min
20h
Understanding the macrosegregations creation - 65 ton ingot - Moving grains

<table>
<thead>
<tr>
<th>Time</th>
<th>ΔC/C₀</th>
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<tbody>
<tr>
<td>1h 15min</td>
<td></td>
</tr>
<tr>
<td>2h 40min</td>
<td></td>
</tr>
<tr>
<td>3h 45min</td>
<td></td>
</tr>
<tr>
<td>20h</td>
<td></td>
</tr>
</tbody>
</table>
Comparison with experimental results - 65 t ingot
Comparison with experimental results - 65 t ingot
Comparison with experimental results - 65 t ingot
Origin of equiaxed grains origin? ECT modeling with Solid

Each structure has its own solid phase, extra- and intra-dendritic liquid phases.

Equiaxed grains are blocked when they enter in a REV with columnar struct. already present

Modelling of Columnar-to-equiaxed and equiaxed-to-columnar transitions in ingots using a multiphase model, *Leriche et all, MCWASP 2015*
Application to a 6t2 steel (Asco Industries)

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>S</th>
<th>P</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt %</td>
<td>1.01</td>
<td>0.23</td>
<td>1.34</td>
<td>0.33</td>
<td>0.11</td>
<td>0.021</td>
<td>0.015</td>
<td>0.03</td>
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</tbody>
</table>

Structures distribution

- Cast iron mold
- Dendritic morphology
- Globular morphology

Mixed structures (branched grains)

PhD T. Mazet 1995
6t2 ingot - Pre process with Solid

Symmetry

Convective + Radiative heat transfer

Adiabatic

refractory

Hot top

ingot

mold

gravity

$D_{eq} = 0.65m$

$H = 2.67 m$
6t2 steel ingot - Evolution of Carb and Temp
6t2 steel ingot - ECT position
Continuous casting application -

- Inoculants moving integration
- Grains size computation
- Thermo-solutal convection
Semi continuous casting Al-Cu

- Thermo-metallurgical stationary conditions set up

Temperature distribution

Cu segregation

Structure distribution

Application Constellium
Summary: **Solid**?

- **Solid** is a simulation software dedicated to casting ingot
- **Solid offers**
  - Multi components alloys
  - Material molding differentiation
  - Filling (simplified approach)
- **Solid predicts**
  - Global process results
  - Casting defaults
  - Segregation and structure correlated to final properties
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