Numerical Simulation of a Shell Forming, From Hollow Ingot to the Final Product With a Powerful Software Tool

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AGENDA

➢ PRESENTATION OF THE CASE STUDY
➢ FILLING AND SOLIDIFICATION SIMULATION WITH CASTING SOFTWARE
➢ MANDREL DRAWING, BECKING AND HEAT TREATMENT SIMULATIONS OF THE SHELL WITH FORGING SOFTWARE
➢ CONCLUSION
CASE STUDY PRESENTATION

- Shells usage and production
  - Shells are used for pressure vessels for nuclear and petrochemical industries
  - They can be produced either from solid ingots, or from rolling-welded products, or from hollow ingots
  - Main advantage of the hollow ingot technology: more savings compared to solid ingots, no welded area compared to rolling-welded process, higher quality of the product

- Interest and simplicity of Casting/Forging models coupling for the design of such component
CASE STUDY PRESENTATION

- Complete case study produced by Transvalor
- Geometries of the hollow ingot and of all the molds inspired by industrial case and literature
  - Material choice, casting conditions, mandrel drawing parameters defined by Transvalor
- 140t ingot
- Standard steel (C 0.40%)
- Flow rate: 3.95 t/min (35.5 min of pouring time, 100 mm/min)
- Initial temperature 1550°C (superheating: 60°C)
### Case Study Presentation

<table>
<thead>
<tr>
<th>Casting</th>
<th>Mandrel Drawing</th>
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<tbody>
<tr>
<td>140 t</td>
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<tr>
<td>3.50 m</td>
<td></td>
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<tr>
<td></td>
<td>3 m</td>
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<td>0.700 m</td>
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<td>2.50 m</td>
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<td>3 m</td>
<td>4 m</td>
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Casting Simulation

- Transformation process of considering phase transition (Liquid->mushy->solid)
- Specific thermo-mechanical behavior dedicated to each phase:
  - Navier-Stokes for liquid
  - Viscoplastic for mushy
  - Elastic-Viscoplastic for solid
- Change of thermodynamic & thermo-physical properties according to the temperature
- Considered mechanical properties according to flow stress curves
- Multi-component segregations
- Deformable exothermic top powder
- Computation launched on multi CPU server
CASTING SIMULATION

- Initial geometry
Casting simulation

- **Thermal exchanges**
  - Between ingot and mold:
    - Specific exchange according to the mold material for the liquid phase
    - Heat transfer coefficient depending on air gap for mushy and solid phase
  - Between mold components:
    - Specific exchange according to the mold component material
  - Between core and ambient:
    - Strong cooling
  - Between external surfaces and ambient:
    - Air cooling

- **Mechanical exchanges**
  - Between ingot and mold:
    - Sticky contact for liquid phase
    - Viscoplastic friction law for mushy zone
    - Coulomb/Tresca friction law for solid (μ = 0.02)
  - At mold components interfaces
    - No friction (rigid mold)
  - Deformable powder
CASTING SIMULATION

➢ Focus on the beginning of filling

➢ Temperature evolution
CASTING SIMULATION

- Carbon segregation evolution
CASTING SIMULATION

Porosities
Casting Simulation

- Ferro static pressure
- vonMises
TRANSFER

- Porosities distribution
- Carbon concentration distribution
Direct transfer from casting process to forging process
- The « end computation » mesh of casting is symmetrized and read by forging software
- Riser and foot are cut through a chaining operation
- Porosities, segregation and elements concentration are transferred from casting as input data for forging

Process parameters defined in order to obtain a relatively long shell with a significant thickness.

Piloting: extension from 3m to 4m
Mandrel Drawing

- Global shape evolution during mandrel drawing
- Porosities evolution
Mandrel Drawing

- Equivalent strain evolution during the forging process

Equivalent strain at 30% of the first pass

Equivalent strain at 75% of the first pass
Prediction of carbon concentration distribution at the end of forging and influence on the TRC curves
BECKING AND HEAT TREATMENT

- Becking process
- Heat Treatment process

Temperature

Temperature during quenching
CONCLUSIONS

- Coupling between THERCAST® and FORGE® allows the design of components like shells, produced from a hollow ingot.

- Porosities, segregations, elements concentration, strains, stresses and others can be calculated in THERCAST® and their respective evolution can be directly carried out in FORGE® until the end of the complete process.

- Optimization of the complete chain of casting and forging processes is so available with this powerful numerical tool.
THANK YOU
FOR YOUR ATTENTION

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