Using numerical simulations to optimize quality and costs in HPDC foundries


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Casting, technology
- Permanent mold (GDC, GDTC, HPDC; LPDC)
- Sand or ceramic mold (GSC, INV)
  - Gravity (G, T)
  - Pressure (HPDC, LPDC)
  - Centrifugal (H, V)
  - Vacuum
  - Continues,

Casting technology
(selection of technology, calculation of gating system, selection of cold chamber set, determining the technological process window (Tp, ...))

Casting of adequate quality

Alloy
(raw material, degree of recycling, melt treatment, way of pouring, Chemical composition, NP)

Type of the mould
(selection of different hot working toll steel, W-alloy, heat treatment, properties)
1st phase
piston motion

2nd phase
die cavity filling - shot

3rd phase
high pressure
1. What is the main problem to pour the molten Al alloy?
   • Solubility of iron in Al alloys
   • Cycle time

2. How to increase the efficiency of working the cold chamber?
   • Decreasing the solidification of molten alloy in chamber (time for phase I and II has to be short, Temperature of chamber high) This cause the new situation which is connect with time for shot (II phase)
   • Increasing the life time of sleeve and piston
   • Increasing of yield of molten metal
What is the main problem to prepare the accurate calculation of casting process for HPDC?

- It is necessary to choose and/or calculate or measure the real material properties: 
  \( T_l, T_s, f_s-f(T), \rho-f(T), \eta_f(T), E, \ldots \)
- The calculation must start in the phase 0
- The description of phase I to III is required for accuracy
- The boundary conditions has to be set properly (T, HTC, t)
- The geometry should be describe with fine mesh
- Technological process window should reflect the real (experimental) data input
HPDC- Cold chamber

Calculation of melt flow and melt temperature drop from furnace to casting chamber

Measurements of melt temperature in the casting chamber before the first stage starts
• Filing of casting chamber calculation compared with experimentally determined temperatures.

• Temperature in the chamber before the shot at 650 °C, temperature of the melt in the casting furnace 677 °C ⇒ temperature drop 20 - 30°C.
Example: Optimization of phase I and II

$V_1 = 0.6 \, \text{m/s}$

$V_1 = 0.3 \, \text{m/s}$

$V_1 = 0.07 \, \text{m/s}$
Example: Cooling of molten metal in the cold chamber in the first phase

When the speed of the first phase is 0,3 m/s hold-wave accures.

When the speed of the first phase is 0,6 m/s we avoid hold-wave. The time from start of the piston movement to switching to the second phase is 0,5 s. In this time the cooling of the melt in the casting chamber is minimal.

When the speed of the first stage is 0,07 m/s the piston travels 4,2 s during all this time the melt is in contact with air and causing large oxides on the surface. At that time there are areas in the chamber where the temperature drops below liquidous temperature.
Investigated geometry of gearbox casting and their gating system

Alloy: AlSi9Cu3

$T_{\text{liquidus}} = 588^\circ\text{C}$

$T_{\text{solidus}} = 508^\circ\text{C}$

Pouring temperature 660 °C

Bruto weight of casting: 7 kg
Neto weight of casting: 4.7 kg
Geometry of tool assembled with cold chamber set

Casting distributor
Surface mesh for FEM analyses
The layout of cooling and heating channels

Fixed side of die

Moveable side of die
Boundary conditions

Heat transfer condition
Temperature
Cycling calculation, fixed side of the toll
Cycling calculation on fixed side of die after 10 cycle

Before the lubrication

At the end of cycle

\[ dT = 369 - 209 = 160 ^\circ C \]
Cycling calculation on fixed side of die after 10 cycle – steady state temperature field
Cycling calculation on moveable side of die for 10 cycles

Insufficient cooling

ProCAST
Cycling calculation on moveable side of die for 10 cycles - steady state temperature field

Proposed solution
Move closer selected part of cooling system to the overheated area of toll
The calculation of normal stresses in the tool

Before the lubrication

At the end of cycle
The calculation of normal stresses in the tool – stable side of the tool

- Solidification
- Lubrication of casting cavity
- Open tool
Optimization of the movable side of the tool

Ver. 1

Ver. 2

Additional fountains
The calculation of the temperature field after 10th cycle

dT=249-165=84°C
Calculation of temperature for variant 1 and 2

\[ dT = 375 - 341 = 34^\circ C \]
The calculation of normal stresses in the tool
Calculation of pouring – different gating system
Calculation of pouring
Calculation of solidification sequence

Fraction Solid

T_1763

Step No / Time Step : 14 / 4.000e-002
Simulated Time : 0.2250 sec
Percent Filled : N/A
Fraction Solid : 0.1

ProCAST
Calculation of solidification sequence versus time
Last solidified areas in the casting

Fraction Solid

$t = 15.2 \text{ s}$
Presented shrinkage porosity areas are not allowed, with local squeezing technique can be eliminated.
Comparison of calculated and experimental shrinkage porosity
Calculation of the stress and deformation for each sequence after the solidification.
Relaxation of normal stresses in the casting after the die opening

Average Normal Stress [MPa]

-64.0
-53.3
-46.7
-40.0
-33.3
-26.7
-20.0
-13.3
-6.7
0.0
6.7
13.3
20.0
26.7
33.3
40.0
46.7
53.3
64.0

closed tool

open tool
Calculation of the shrinkage of the casting and the formation of an air gap between the solidification.
Deformation of casting

Note: Reference is sliding away tools

Fixed side of tool

Moveable side of tool

The deformation of the casting at 20 x magnification

Step No / Time Step : 0 / 1.0000e-002
Simulated Time : 0.0000 sec
Percent Filled : N/A
Fraction Solid : 0.0
Relaxation of normal stresses in the casting

Relaxation of stress after ejection of casting

open tool

ejection of casting
The deformation of the casting in Y direction

open tool
ejection of casting
Calculation of the temperature field for the cooling of the cast part in the water
Deformation during submerging cast part in the water

We can see how the casting during the cooling in water is deformed downward.

The deformation of the casting at 15 x magnification

Note: Reference is a biscuit
Deformation of casting, after cooling in water.
Technology optimization - distributor
Temperature in critical area was in ver. 1 235,3 °C, with new cooling system the temperature was 94,7 °C. Temperature drop with new cooling system was 60 %. Stresses with new cooling system were lower for 47 %.

Distributor with version 1 cooling system made 65080 cycles, new distributor made 79129 cycles. Life time prolonged for 21 %.
Including numerical simulations in early technology development phase can reduce costs:
- optimal casting technology can be defined before real testing
- casting defects under acceptable limits
- finding critical areas during design phase

With adequate process and technology optimization it is possible to:
- prolong the dies lifetime
- shorten production cycle of casting

The time from order to prototype products can be reduced.
SREČNO!

Good luck!