THERMO-FLUID DYNAMICS MODEL OF TWO-PHASE SYSTEM ALLOY-AIR INSIDE THE SHOT SLEEVE IN HPDC PROCESS

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Abstract

In HPDC process, the final quality of castings is highly correlated to the first stage of injection. During this phase, the movement of the melt due to plunger's acceleration causes the high level of air entrapment, inducing porosity into the component. This has a detrimental effect on mechanical properties and produces internal and surface defects.

To prevent these phenomena, it is important to control all the relevant process parameters. In the present work, this objective has been achieved through the development of a model that describes the thermo-fluid dynamics behavior inside the shot sleeve. The model consists in:

- **Numerical model**: implementation of thermal equation into an open source CFD code;
- **Mathematical model**: generation and execution of a DOE. The developed code has been used to simulate several cases with different combinations of input parameters.

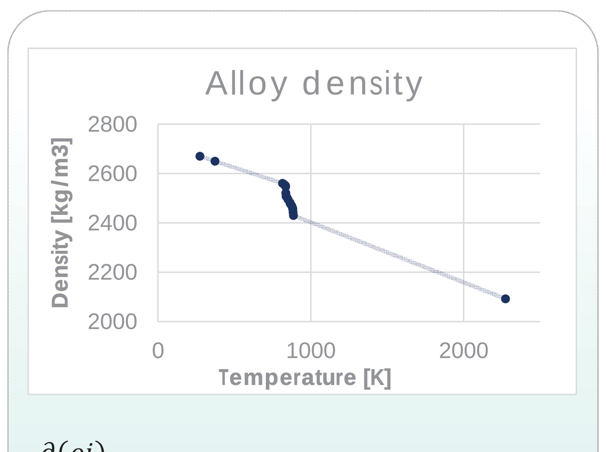
The models allow to determine the response surface that is used to analyze the percentage of trapped air.

The activity has been conducted for the master thesis work.

Numerical Model

Scope

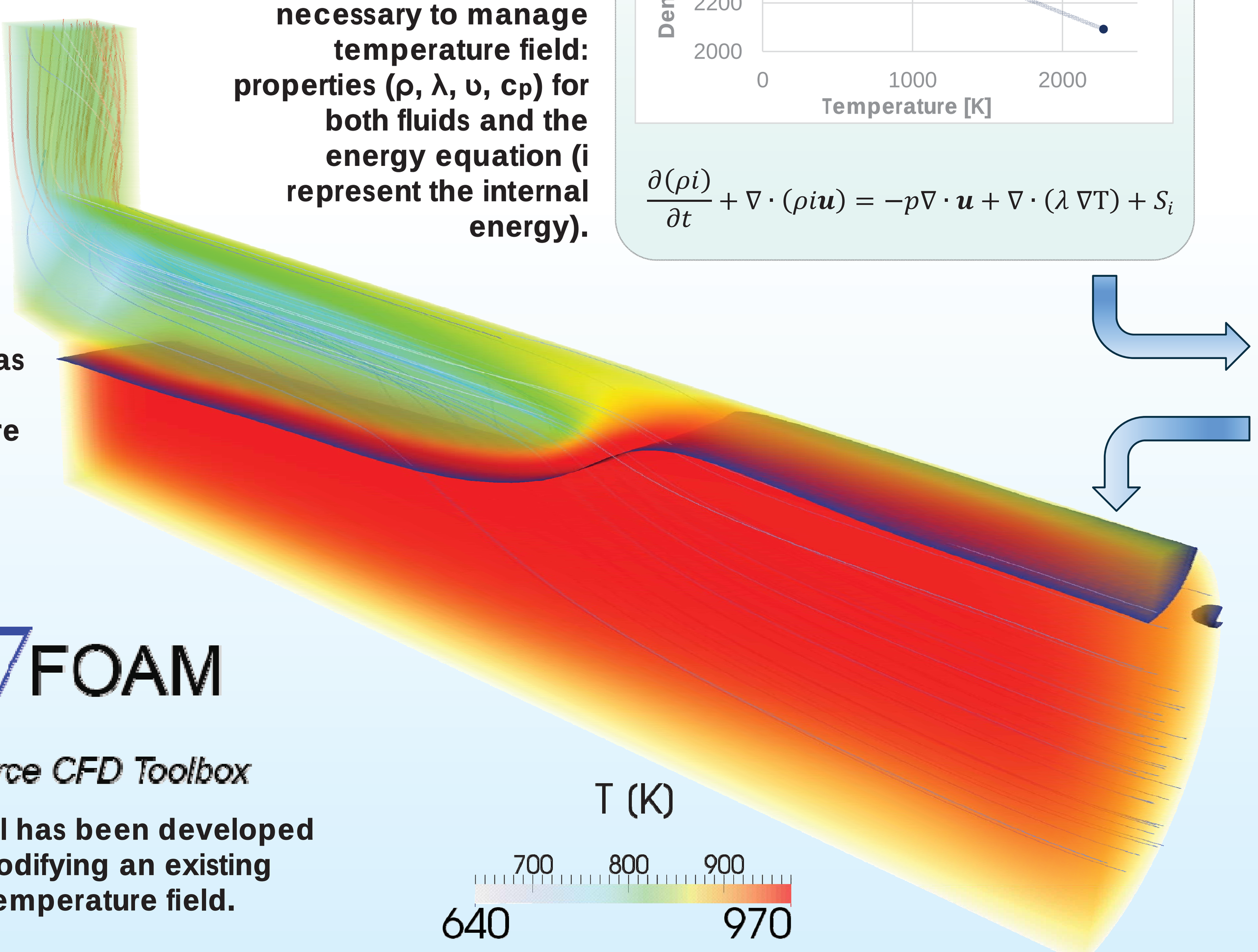
Development of a numerical model that describes the dynamic of the system inside the shot sleeve also considering the heat exchange.



$$\frac{\partial(\rho i)}{\partial t} + \nabla\cdot(\rho i \mathbf{u}) = -p\nabla\cdot\mathbf{u} + \nabla\cdot(\lambda\nabla T) + S_i$$

Example of new inputs necessary to manage temperature field: properties (ρ, λ, υ, c_P) for both fluids and the energy equation (i represent the internal energy).

3D view of computational domain used to describe the system inside the shot sleeve. As can be seen, only a half of cylinder has been implemented. This frame shows temperature field, separation surface and that highlights local fluid flow.



OpenFOAM

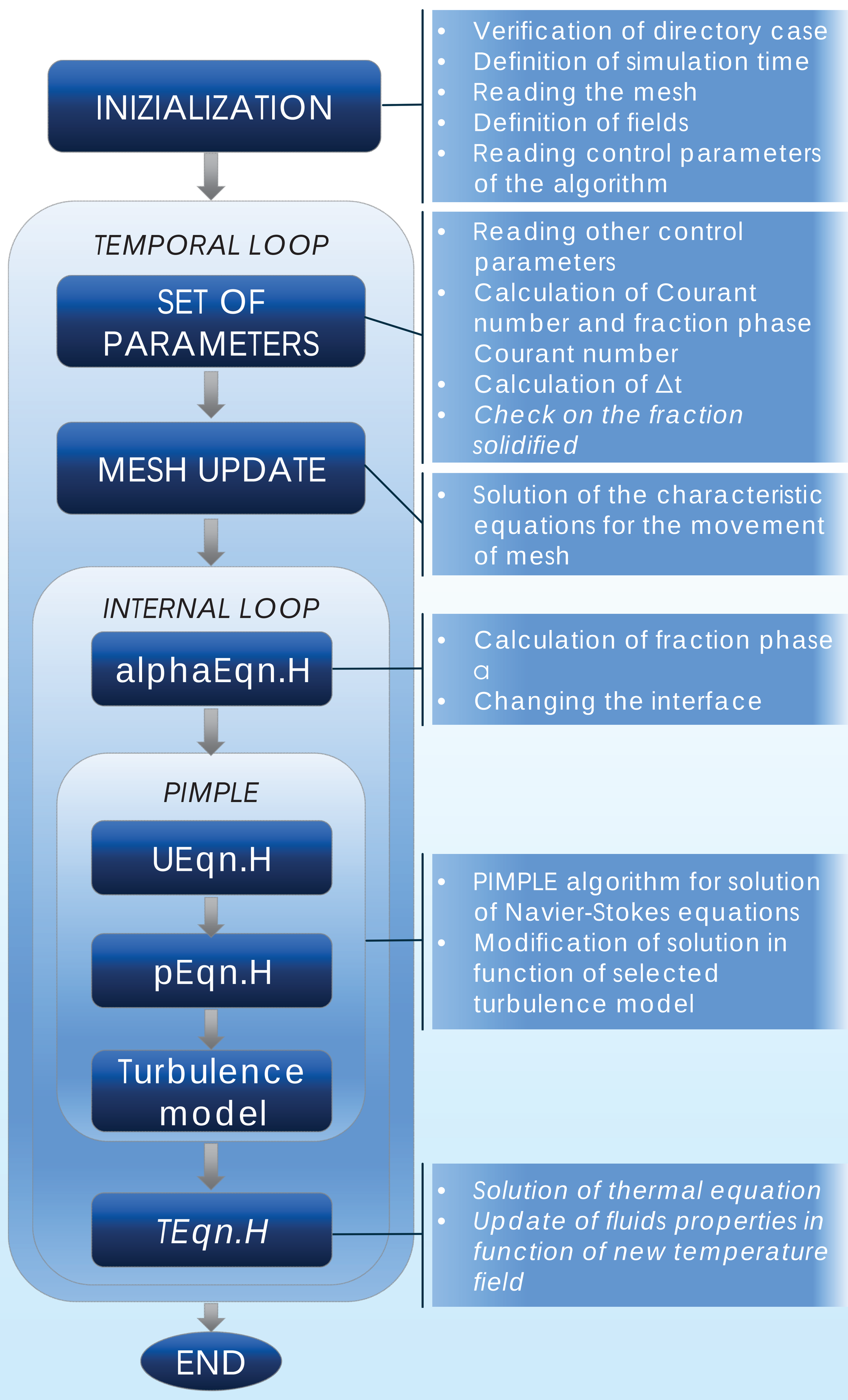
The Open Source CFD Toolbox

The numerical model has been developed in OpenFOAM, modifying an existing solver to add temperature field.

Original Solver: interDyMFoam → Multiphase flow → Incompressible fluids → Dynamic mesh

Modified solver: myinterDyMFoamDiabatic → Multiphase flow → Incompressible fluids → Dynamic mesh → *Heat exchange*

An existing solver, *interDyMFoam*, has been used as a basis for this project. The figure shows physical phenomena that are taken into account for the original solver and modified one. Heat exchange has been introduced adding two main features: computation of temperature field and temperature dependent fluid properties such as viscosity and density.



Algorithm for the numerical model implemented into a CFD code. Parts in italic font represent changes to the original solver.

Mathematical Model

a) MODEL DESIGN

Scope

Identification of the relevant process parameters which will constitute the input variables for DOE and parameterizing the model as a function of these.

Process parameters selected

1. **D** = inner diameter of the shot sleeve;
2. **L** = length of the shot sleeve;
3. **F** = initial filling of melt.
4. **V** = velocity of the first phase;

Geometry

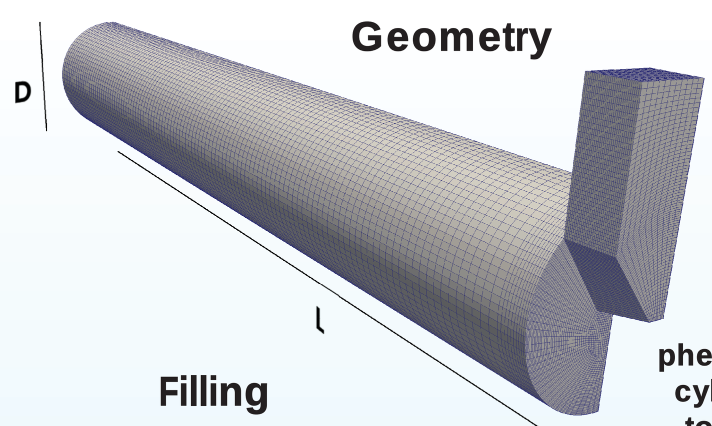
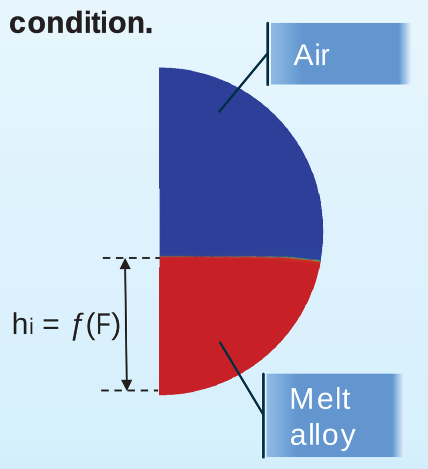


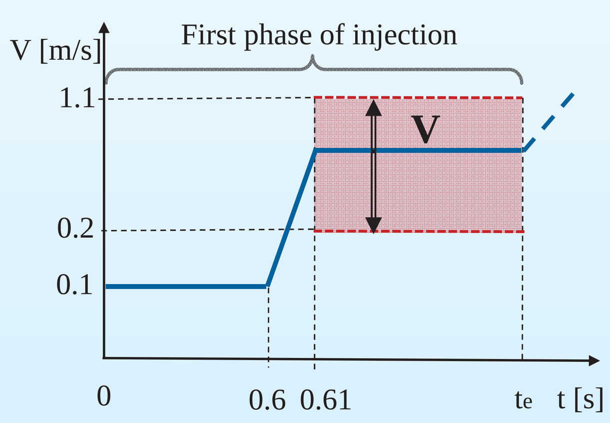
Figure shows the computational domain. Geometry model has been parameterized with D and L variables only. A mapped mesh has been employed for properly describing fluid flow phenomena. Finally, only half cylinder has been simulated to save computational time imposing symmetry condition.

Filling

Initial filling represent the quantity of melt alloy. With this value it is possible to calculate height of its free surface and using it as variable for set initial condition.



Velocity profile



The shot profile of first phase presents a section with reduced speed to avoid leakage and a second section at a constant velocity V.

Other consideration

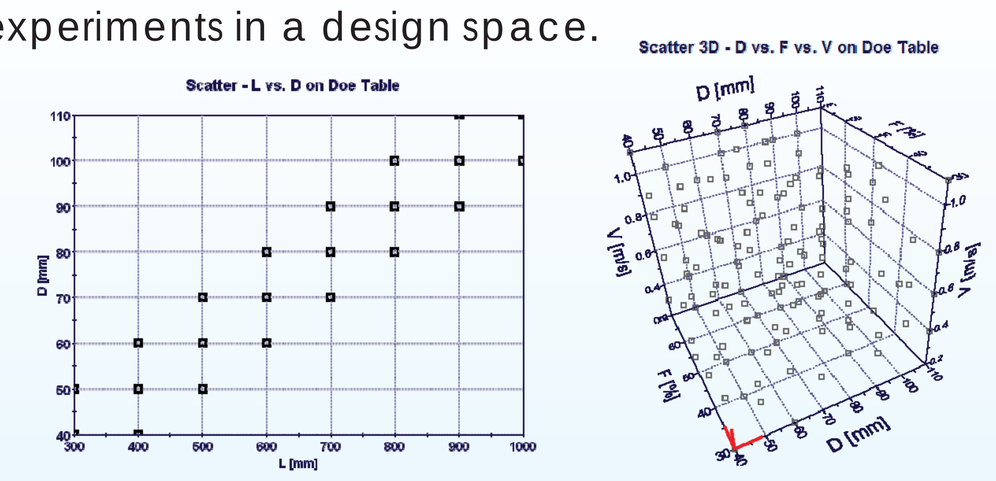
All the remaining variables have been set as a function of four previous input parameters. It has been necessary to define a reliable and consistent condition for the end time of the simulations. The aim is to properly compare the results of trapped air volume percentage for different cases: simulations end when the total volume of the cylinder equals the initial volume occupied by melt alloy.

b) DEFINITION & EXECUTION OF DOE

In this phase of project, modeFRONTIER® has been used as the basis for the DOE planning but not for DOE execution.

DOE definition

Each input variable range with a fixed quantization step. To avoid unfeasible designs some constraints have been imposed on combinations between input variables. In this way only the relevant cases in foundry practice have been simulated. SOBOL algorithm has been adopted to uniformly distribute a given number of experiments in a design space.



Two example graphs that show the distribution of experiments in the design space. The graph on the left gives the idea about the constraints imposed on the geometric variables. These designs has been written into an excel spreadsheet, reported below.

Number of designs: 151 — UPDATE DOE

DOE inputs					SIMULATIONS RESULTS			
Design	D [mm]	L [mm]	F [%]	V [m/s]	VtotFin [m3]	ValumFin [m3]	Air entrapment [cm3]	R
d0001	100	900	60	0.2	0.002108198	0.002014747	1.87E+02	4.433%
d0002	90	700	40	0.2	8.82E-04	8.70E-04	24.88	1.410%
d0003	110	900	50	0.7	0.002123017	0.002087773	7.05E+01	1.660%
d0004	100	800	60	0.9	0.001873512	0.00184102	6.50E+01	1.734%
d0007	60	600	50	0.4	4.21E-04	4.17E-04	9.45	1.121%
d0008	100	1000	30	0.9	0.001168032	0.001126441	8.32E+01	3.561%
d0009	90	900	50	0.6	0.00142322	0.00140327	3.99E+01	1.402%
d0010	50	500	30	1.1	1.46E-04	1.39E-04	13.32	4.570%
d0011	70	700	70	0.4	9.39E-04	9.31E-04	16.36	0.871%
d0012	40	400	60	1	1.50E-04	1.48E-04	3.54	1.181%

Excel spreadsheet that reports all designs. Inputs are read by modeFRONTIER®, the outputs are returned by OpenFOAM.

DOE execution

It has been necessary to work out some scripts automatically generating all the experiments by reading variables from a text file. These cases have been executed on a **cluster system** which enables to run several designs at a time using several processor.

c) APPLICATION OF RSM (Work in progress)

The rate of entrapped air (**R**) has been calculated by dividing the final volume of air (**V$_{air}$**) respect the final total volume (**V$_{tot}$**). After inserting these values in modeFRONTIER®, it has been possible to apply *Response Surface Methodology* (RSM) which correlates input variables with the related output by means of a mathematical model. *At the moment, the simulations are running and so the results are partial.*

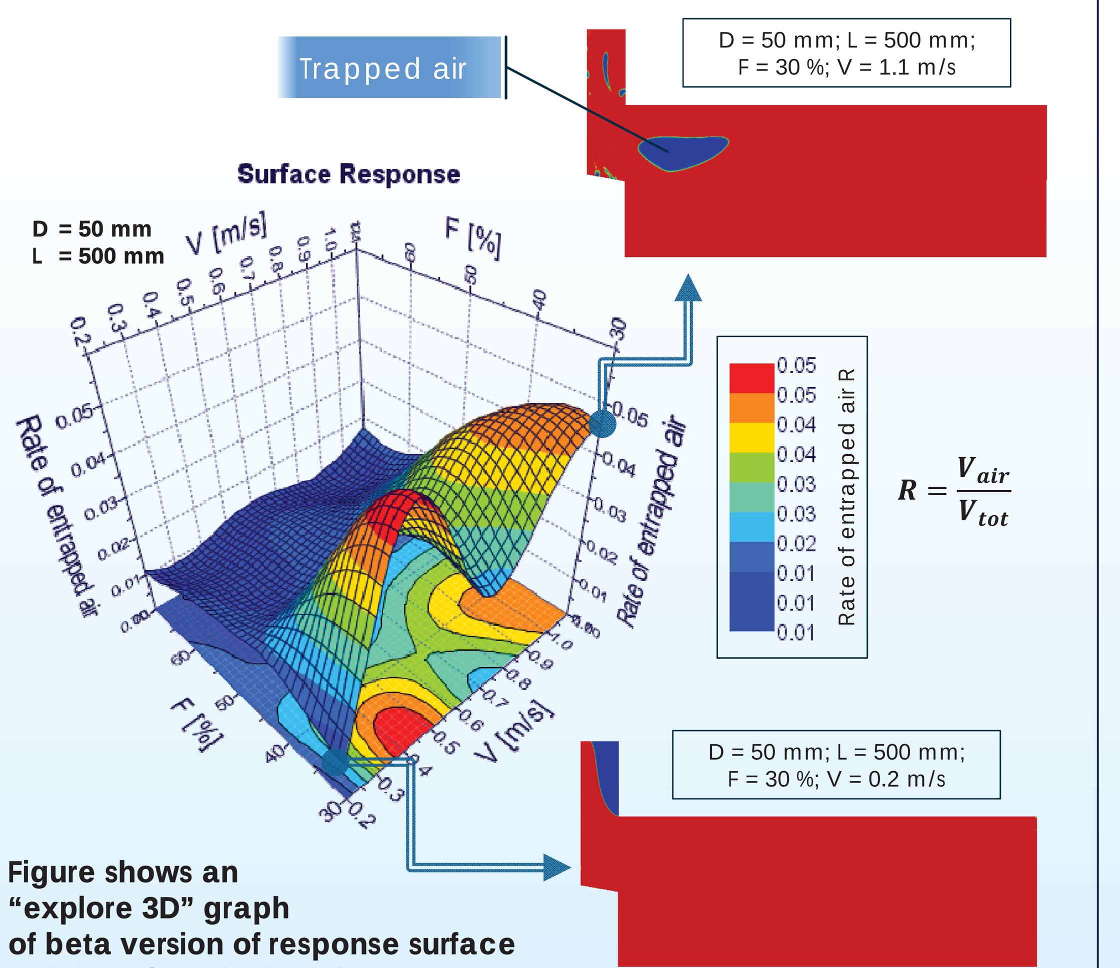


Figure shows an "explore 3D" graph of beta version of response surface (Kriging algorithm) and two shot sleeve images at final time of the simulation. These allow to compare the results in terms of trapped air keeping constant the initial filling at 30 %. As you can see, with these geometric parameters, no entrapment is present at low speed (V = 0.2 m/s).

Future aim

With this tool, it will be possible to explore all the combinations of input parameters (within the given ranges) and to forecast trapped air. This would support HPDC engineers in managing process parameters.

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