# Phd position 2024- CEMEF

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| Title | ***Thermochemistry of powders for ingot casting*** |
| *Acronym* | TheCAP |
| Framework | Project carried out within the 2MS team (Metallurgy, Mechanics, Structures & Solidification) of CEMEF (Center for Material Forming, Mines Paris, PSL University).<br>The PhD student will be supervised by researchers from the 2MS team, and will benefit from CEMEF resources, as well as the associated training. |
| *Global objective of work* | Modelling of the thermochemical evolutions of casting powders used for ingot casting, as part of the ANR project TheCAP (Thermochemistry of ingot CAsting Powders) including the CEMHTI academic laboratory (Extreme Conditions and Materials: High Temperature and Irradiation) and various industrial partners from the sector of metallurgy (ARCELORMITTAL, APERAM, ASCOMETAL, AUBERT&DUVAL, INDUSTEEL), as well as two software development companies (TRANSVALOR, SCC). |
| Context | Steel is generally produced using the continuous casting process. However, for specific steel grades, for large forged products and for low-volume niche markets, such as those associated with the aerospace, nuclear, automotive or defence sectors, the bottom pouring process (i.e. feeding by the lower part of the ingot mould) remains the only possible process. In such conditions, the liquid steel must be protected by a layer of mineral powder, called casting powder, as shown in figure (a). This powder partially melts to form a film of liquid slag covering the upper surface of the metal, the rest remaining in powder form. This powder and this coating meet different objectives:<br><br>• protect the liquid metal from oxidation by the ambient air (chemical insulation),<br>• “lubricate” the interface between the solidifying metal and the mould,<br>• thermally insulate the upper surface of the metal (meniscus),<br>• absorb non-metallic inclusions in steel. |

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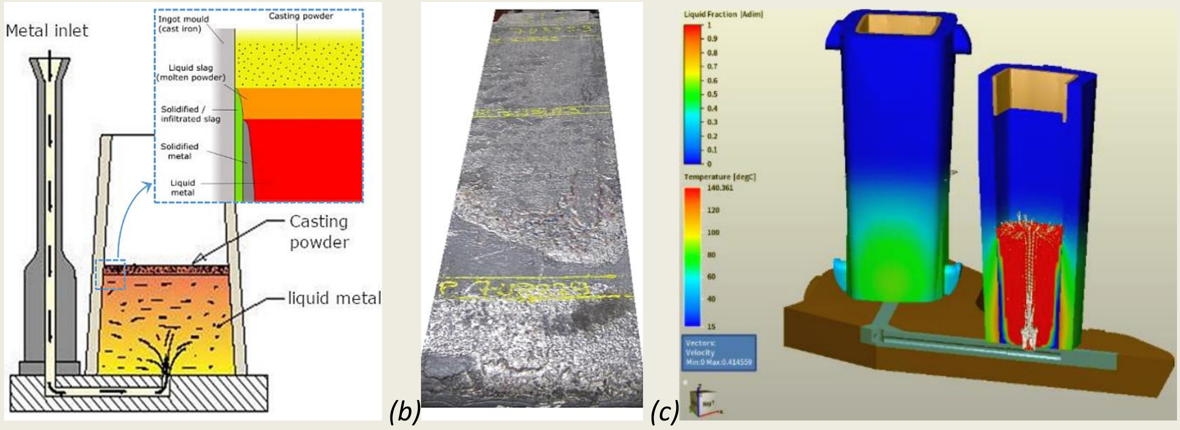


(a) (b) (c)

*Bottom pouring process and its modelling: (a) diagram of ingot casting with enlargement of the region where different domains of interest are in contact, (b) surface of a stainless steel ingot of length 1.4 m cast using low carbon powders, (c) software prediction of the process on a 4.2 ton ingot.*

Through its multiple actions, the casting powder acts directly on the final quality of the ingot. This effect is visible in figure (b) where a stainless steel has been solidified using bottom pouring process. The consequence of an unsuitable powder is the presence of marks and irregular profiles on the skin of the ingot, with adverse consequences on the metallurgical and mechanical in-use properties. The objective of the ANR project TheCAP is to complete the numerical modelling of the casting visualized in figure (c) by including a description of the thermochemical evolutions of the casting powders and their transformations during the process, thus aiming at a better definition of their formulation, their use, and an improvement in the efficiency of the industrial process by reducing scrap resulting from the cutting of the skin of the ingots.

**Detailed presentation**

CEMEF has been involved in the development of industrial codes to monitor, control and optimize the different stages of ingot casting processes [1]. As part of the TheCAP project, a numerical modelling of the phase transformations undergone by the powder bed will have to be carried out. After being spread on the molten metal [2], the casting powder undergoes partial melting. Chemical reactions with the liquid metal take place. Few works exist to model the evolutions of this powder [3, 4]. The PhD project will focus on developing modelling by front tracking method to assess how the different domains of the casting powder interact with the molten metal and the mould during process, as shown in the insert of the figure (a).

A unidirectional multilayer numerical model belonging to the PhysalurgY calculation library [5] will be extended on the basis of the energy and solute mass conservation equations. The number of domains will be defined according to the experimental observations. The chemical reactions will be considered for the computation of the composition profiles. Strong interaction with the academic and industrial partners is expected. The complete model will benefit from the measurements of the powder properties depending from the temperature carried out at CEMHTI and ARCELOMITTAL and from the casting experiments developed by the other partners. At the end of the project, the results of the numerical developments should make it possible to define a simplified equivalent boundary condition, associated with the powder and its evolutions, for application to the upper surface of the cast ingots during the macroscopic simulation of the process, such as shown in figure (c).

**Bibliography references**


[1] J. Dairon, FUI AAP15 Project COMCEPT. Final report (2019).
[2] S. Riber, Méthodes numériques pour la simulation des écoulements de matériaux granulaires par

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| | une approche continue, Doctorat en Mécanique numérique et Matériaux, Mines Paris – PSL, 2017<br>[3] V. N. Neelakantan, S. Sridhar, K. C. Mills, D. Sichen, Mathematical model to simulate the temperature and composition distribution inside the flux layer of a continuous casting mould, Scandinavian Journal of Metallurgy 31 (2002) 191.<br>[4] M. Supradist, A. W. Cramb, K. Schwerdtfeger, Combustion of carbon in casting powder in a temperature gradient, ISIJ international 44 (2004) 817.<br>[5] PhysalurgY, bibliothèque de calcul CEMEF, https://physalurgy.cemef.mines-paristech.fr |
| Diffusion | Communication in national and international congresses<br>Publication in scientific journals in the field<br>Implementation in THERCAST® and SOLID® calculation codes |
| *Tools* | PhysalurgY library: thermodynamic calculation, front monitoring method, description of metallurgical transformations (PY library) |
| Key-words | Ingot casting, casting powder, Solidification, Phase transformation, Front tracking, Thermodynamic coupling |
| Skills, abilities requested | Engineer or Master 2, in the fields of materials, mechanics or applied mathematics. Student attracted by topics related to modelling and numerical simulation of physical phenomena and engineering science.<br>The PhD student will also receive the training necessary for his research activities in the field of materials science, as well as in the field of scientific computing and programming, in particular to master the dedicated computing tools. |
| Gross annual salary | 28,5k€ |
| Location | CEMEF, Sophia Antipolis (Site de Mines Paris - PSL) |
| CEMEF team | Metallurgy, Mechanics, Structures & Solidification – 2MS |
| Supervisor(s) | Charles-André GANDIN (charles-andre.gandin@minesparis.psl.eu)<br>Gildas GUILLEMOT (gildas.guillemot@minesparis.psl.eu) |

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