30 August 2024

PhD contract offer

Direct numerical modeling of mesosegregations during the solidification of low alloy steels

General information

Workplace: Nancy, France
Type of contract: CIFRE PhD contract
Contract period: 36 months
Expected date of employment: December 2024
Proportion of work: Full time
Remuneration: 35–40 k€
Desired level of education: Master's degree in mechanical engr., physics or materials science

Project description

Background

The heavy components present in the primary circuit of a nuclear reactor (pressure vessel, steam generator, pressurizer) are made of forged and welded low-alloy steel parts. The chemical composition of the cast ingots used for forging is not uniform, they contain chemical heterogeneities, called segregations. These segregations cannot be entirely removed during the manufacturing process. Forged parts therefore contain local variations of chemical composition, which may significantly affect the mechanical properties. To limit these segregations is an important objective for FRAMATOME, one of the world's major nuclear reactor constructors. Segregations at the scale of the ingot (*macro*segregations) have been studied for a long time. Segregations at a local, mesoscopic scale of 1–10 mm (*meso*segregations), as well as the resulting segregation bands in the forged part, were recently characterized experimentally for the first time, using X-ray microfluorescence (PhD thesis of Lucie Gutman, 2024). Insight into the mechanism of formation of mesosegregations is the next step towards an improvement of the chemical homogeneity of the cast and forged parts.

Objectives of the PhD

The objective of this project is to analyze the mechanisms of formation of mesosegregations and to propose realistic means for reducing them. Mesosegregation patterns are about the same size as the crystal grains that make up the material. They form during the solidification of the material and their formation is governed by convection of the chemical species with the flow of liquid and by diffusion. These species transport phenomena are strongly coupled with the growth of the solid grain structure. The size and shape of the individual grains must be therefore accounted for in a comprehensive theory of mesosegregation.

In this project we aim at proposing a theory of mesosegregation using numerical simulations of the underlying transport and solidification phenomena. This will be achieved using state-of-the-art mesoscopic solidification models, such as the Grain Envelope Model (GEM) or the Voronoi Granular Model (VGM). These models can describe the grain growth, coupled with flow of the liquid between the grains, with heat transfer, and with diffusion and convection of the chemical species. They can simulate around a hundred (GEM) or tens of thousands (VGM) of grains. They are based on CFD solution methods (finite volume, finite element) for the transport equations, coupled with models of liquid-solid phase change. The models will be able to investigate the impact of the solidification conditions on the evolution of mesosegregations and help to formulate mesosegregation-risk criteria that can be incorporated into macroscopic process-scale models of casting.

Finally, the numerical models will be used to explore the possibilities of reducing the intensity of mesosegregation by modifying the chemical composition of the steel. The modeling study will be compared to experimental characterizations that will be performed in parallel.

Application of results

This PhD aims at proposing realistic measures and modifications of the casting practice in the casting plant. The ingot producer ArcelorMittal Industeel will therefore be informed of the project advancement. The project will also benefit from the environment of the Industrial Chair on Solidification at the Institut Jean Lamour in Nancy. Part of the results will be published.

Work environment

The PhD student will be employed by Framatome on a CIFRE PhD contract. The PhD student will work at Institut Jean Lamour in Nancy under the supervision of Drs. Miha Založnik, Jacob Kennedy, and Julien Zollinger, experts on solidification of metal alloys. She/he will be part of the *Solidification* group and will benefit from an interdisciplinary scientific environment: materials science, metallurgy, heat & mass transfer, computational modeling, experimentation and characterization at laboratory and industry scale. He/she will regularly meet with collaborators at Framatome in Paris and will occasionally interact with the ArcelorMittal Industeel steel plant and with the Framatome Technical Center in Le Creusot.

Skills

- Master's degree in mechanical engineering, materials science or physics.
- Good notions of heat & mass transfer, phase change, fluid dynamics, and numerical methods.
- Experience in numerical modeling (finite volume method appreciated).
- Proficiency in computer programming (C++, Python, OpenFOAM®).
- Proficiency in technical report writing and presentation.
- Sense of initiative, problem-solving and teamwork skills.
- Fluency in English, some knowledge of French is beneficial.

Constraints and risks

The position is in a sector relating to the protection of scientific and technical potential. It therefore requires, in accordance with the regulations, that your arrival be authorized by the competent authority of the Ministry of Higher Education, Research and Innovation.

About Institut Jean Lamour

The Institut Jean Lamour (IJL) is a joint research unit of CNRS and Université de Lorraine. **Focused on materials and processes science and engineering, it covers: materials, metallurgy, plasmas, surfaces, nanomaterials and electronics.** It regroups 183 researchers, 91 engineers, technicians, and administrative staff, 150 doctoral students and 25 post-doctoral fellows. Partnerships exist with 150 companies and our research groups collaborate with more than 30 countries throughout the world. Its exceptional instrumental platforms are spread over 4 sites; the main one is located on the Artem campus in Nancy.

Application

To apply, send us a short statement of your interests, your CV, and full academic transcripts of the last two years of your master's studies.

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