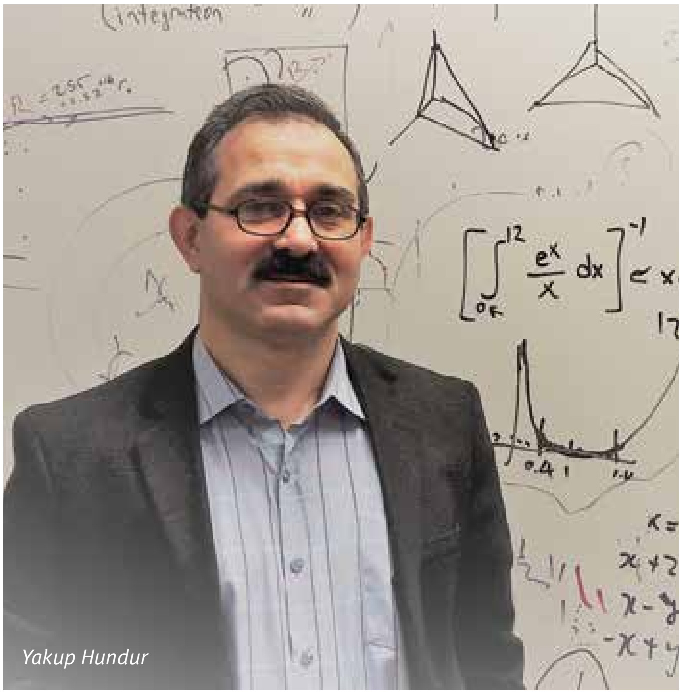
Electromagnetic stirrer simulations for the steel industry

Moving away from their in-house computing capabilities, Italian SME Ergolines is employing supercomputing facilities provided by PRACE to radically improve the steel casting process. The SHAPE Project was jointly led by Dr Ahmet Duran and Dr Yakup Hundur from Istanbul Technical University (ITU), and Ergolines' scientific team, to simulate the complex geometries that will help to improve Ergolines' design and product development

In the steel making industry, advanced technologies are needed to optimise the different stages of the steel casting process. In continuous steel casting, dedicated electromagnetic stirrers (EMS) can be used in the very first stage of the process to optimise energy consumption during the melting of metal scrap within the electric arc furnace (EAF). Aside from improving the homogeneity of the heat distribution in the furnace, the use of EMS enhances the casting process overall to reduce furnace wear, boost efficiency and optimise costs and productivity.

Ergolines s.r.l. is a world leader in the design of EMS for continuous steel casting. Based in Italy, Ergolines has teamed up with experts from Istanbul Technical University (ITU) to exploit the HPC capabilities of CINECA's Fermi supercomputer in order to further optimise the design of EMS. Dr Ahmet Duran and Dr Yakup Hundur, associate professors at ITU's departments of mathematical engineering and physics engineering respectively, approached this using magnetohydrodynamic (MHD) simulations to combine electromagnetics and fluid dynamics.

Discretising the melting of steel in an EAF is not a simple task. Firstly, there are geometrical constraints to analyse, then the calculation of electromagnetic performance, simulation, and finally parameter optimisation and calibration. As an iterative multiple simulation process, the calculation of electromagnetic performance, fluid dynamic simulation, and parametric calibration are repeated until the required electromagnetic performance is achieved. Before working with ITU, Ergolines used its own in-house OpenFOAM codes to run simulations that took approximately 15 hours. Open FOAM is an open source software dedicated to computational fluid dynamics (CFD). Through the SHAPE programme, the Fermi supercomputer dramatically reduced the computational time of the simulations. With it, 15-hour simulations are cut down to 20 minutes. Such dramatic reductions in time scales mean a great deal, allowing for much more experimentation and fine tuning for an optimised product. By taking advantage of their consolidated experience with international research projects on multi-physics simulations for industrial applications, Ergolines and ITU cooperated by exploiting their respective CFD and MHD competencies. The work required people with experience in physics, mathematics, mathematical modelling, mechanical engineering, HPC programming and design, and also industrial application.



Yakup Hundur

Ahmet Duran

Fluid-dynamic simulation: velocity field displayed as flux lines

In this project, the Ergolines and ITU teams used finite element method (FEM) simulations to break down the larger problems into smaller, simpler parts on a mesh. Ergolines' scientific team was composed of Isabella Mazza, Cristiano Persi and Andrea Santoro. Mehmet Tuncel, Duran's student at ITU, also provided significant contributions to the project. Supercomputers allow you to create finer meshes which are useful for solving problems, but with finer meshes come higher computational costs. Per mesh, they used three million finite elements. Here, scalability is of vital importance. A software package with no scalability cannot be used in industry. It should be possible to tune both the electric parameters, like current and frequency, and the process parameters.

"Ergolines expects up to a 10% increase in their annual returns so it has made them more competitive in this area"

Another area that required particular attention was the choice of domain decomposition methods and how parallelisation affects computational performance. There are two domain decomposition methods: simple and hierarchical, both of which were tested.The simple method produces a mesh where the number of elements per unit volume is, in general, not the same for all the elements. This implies an unbalanced load distribution for the cores. This approach, however, is suitable for geometries that are simpler than those used in this project. The hierarchical method, on the other hand, can handle complexity better, and the shape of the domain that represents the EAF is indeed complex. The hierarchical method produces a mesh on which the number of elements per unit volume is constant, meaning it is possible to efficiently distribute the computational load between the cores. For ITU and Ergolines, this means they can obtain superior performance in terms of speed-up and computational time.

Ergolines and ITU were able to obtain scalability until 512 cores, but used over a thousand. This allowed the dramatic reduction in simulation times that are so beneficial to Ergolines' experimentation, affording rigorous analysis of the fluid-dynamics of liquid steel when it is under the influence of EMS. This wealth of data can be used by Ergolines to optimise their customised EMS designs for a more efficient and cost-effective industrialisation process. Overall, both PRACE and the European Commission have recognised the project as a great success. Ergolines expects up to a 10% increase on their annual returns, so the project has made them more competitive in this area.

Beyond 512 cores, however, speed-up growth-rate gradually decreases to a saturation point. The ITU team would like to explore this area further with even finer meshes. Instead of three million elements per mesh they could use ten million or higher, allowing them to extract even more information from the simulations. There is the possibility of increasing the number of iterative multiple simulation processes. Finally, the simulations carried out at on Fermi concentrated on the first phase of the casting process. Furthermore, Duran is interested in exploring the solidification stage as well, by using other HPC codes and simulations. The project partners at PRACE, Ergolines and ITU have all expressed an interest in future collaborations and, as illustrated by the partners, there are plenty of avenues in the steel making process yet to explore and build upon with HPC.

For more information

www.ergolines.it
www.prace-ri.eu/IMG/pdf/WP214.pdf
web.itu.edu.tr/aduran
web.itu.edu.tr/hundur

Resources awarded by PRACE

This project was awarded 250 000 core hours on Fermi hosted by CINECA, Italy; 200 000 core hours on Curie hosted by GENCI at CEA, France; and 250 000 core hours on JUQUEEN hosted by GCS at JSC, Germany, under the 21st cut-off of PRACE Preparatory Access which supported the Second Call of PRACE's SME HPC Adoption Programme in Europe (SHAPE)

Publications

Isabella Mazza, Ahmet Duran, Yakup Hundur, Cristiano Persi, Andrea Santoro, and Mehmet Tuncel, HPC-based Design of a Novel Electromagnetic Stirrer for Steel Casting, in EU Horizon 2020 - PRACE 4IP, white paper, WP214, April 2016.