Temperature of steel during hot rolling process

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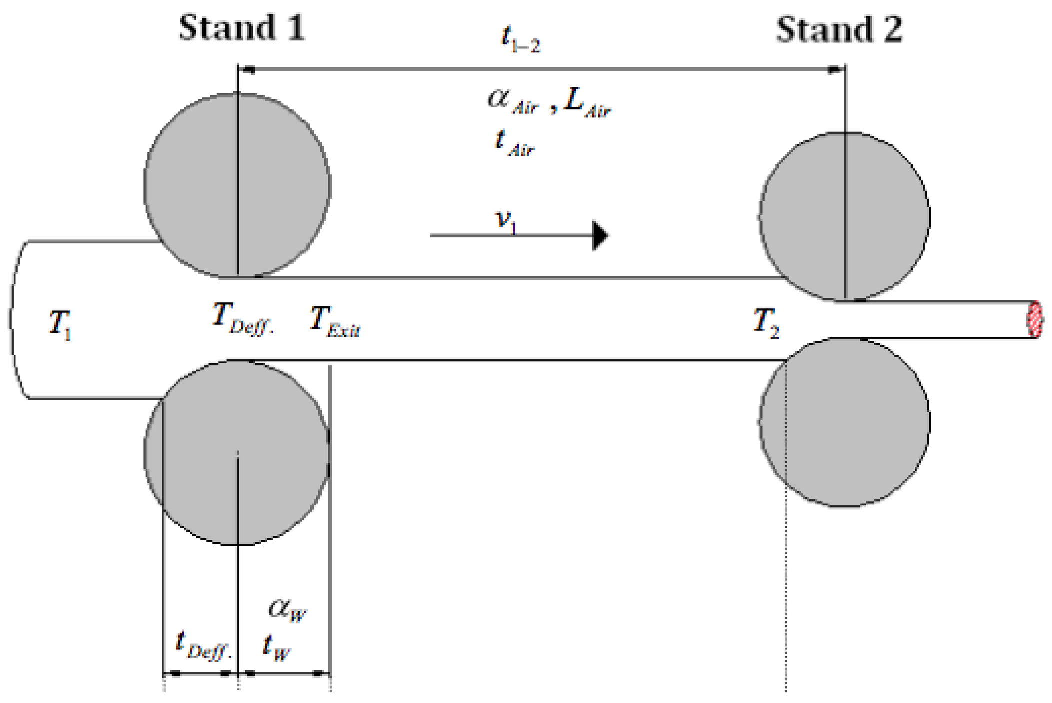
Introduction

One of the challenges of simulating metal-shaping processes is finding a balance between a accurate solution to the problem and the computational cost of the simulation. In this project, the temperature of steel during hot rolling process is simulated using Finite element method (FEM) in combination with a analytical model describing the deformation energy.

Modeling shape rolling is a multi-faceted process. The steel is pressed though a series of rollers that reshape the billet. When the hot steel moves through the steel mill the heat transfers to the air following Newtons law of cooling along with radiation to the surrounding environment using Stefan-Boltzmann law. When the steel passes the rollers the strain give rise to flow stresses which in turn increase the energy in the form of heat. The flow stress is calculated using the Johnson-Cook material model. The heat contribution is then distributed over the material cross section.



Aim

The aim of this project is to simulate the temperature of steel during hot steel rolling in such way that it is not computationally expensive but still provide accurate results.

Model description

$$\begin{cases} c(u)\rho(u)u_t & = \nabla \cdot (k(u)\nabla \cdot u) + Q & , x \in \Omega \\ -k(u)(\nabla \cdot u)\hat{\mathbf{n}} & = \alpha(u-u_0) + \epsilon\sigma(u^4 - u_0^4) & , x \in \partial\Omega \\ x \in \mathcal{R}^2 \end{cases}$$

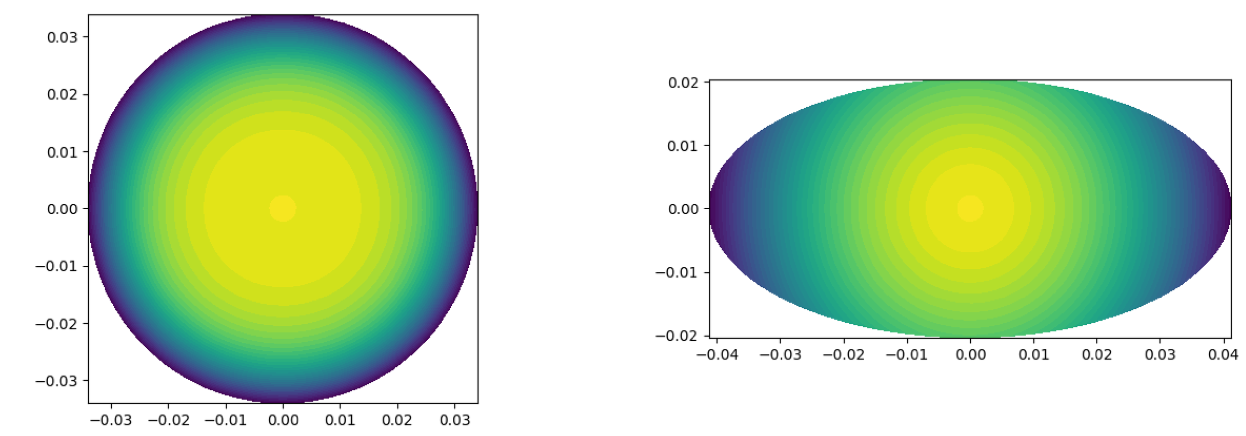
The model describes a 2D cross-section traveling through the mill. k is the heat conduction coefficient, ρ denotes the material density and c the specific heat. Different values of the heat transfer coefficient α is used for the rolls and the surrounding air. Q denotes the temperature increase due to deformation. The boundary conditions are governed by Newtons law of cooling and radiation related to the ambient temperature.

$$Q = \chi(u)\frac{\bar{\sigma}_{jc}\bar{\dot{\epsilon}}}{\rho(u)c(u)}$$

$\bar{\dot{\epsilon}}$ denotes the mean strain rate during contact with the rolls, $\bar{\sigma}_{jc}$ is the mean flow stress calculated using a tuned Johnson-Cook material model. χ denotes the temperature dependent fraction of heat converted deformation energy. Q is projected and assigned to the solution prior to contact with the rolls.

Interpolation of the heat distribution

When the steel is reshaped by the rollers the old heat distribution must be refitted to a new mesh. We solve this problem using the Levenberg-Marquardt optimization algorithm to fit the heat distribution to a function. The new solution is then tuned to give a consistent mean temperature.



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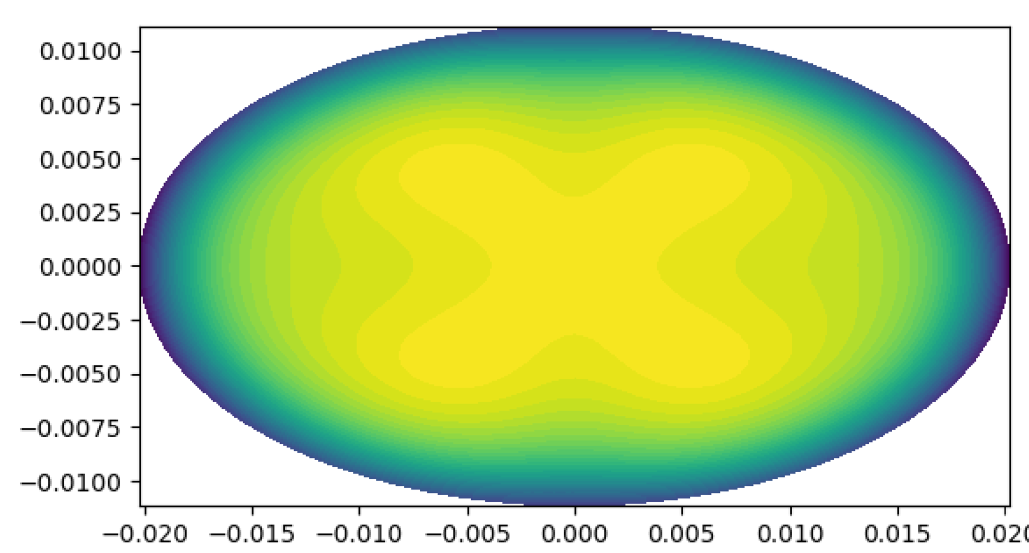
Distribution of deformation energy

The analytical equations describing the deformation energy is distributed on the cross section of the material. The figure below shows the distribution after some small amount of time.



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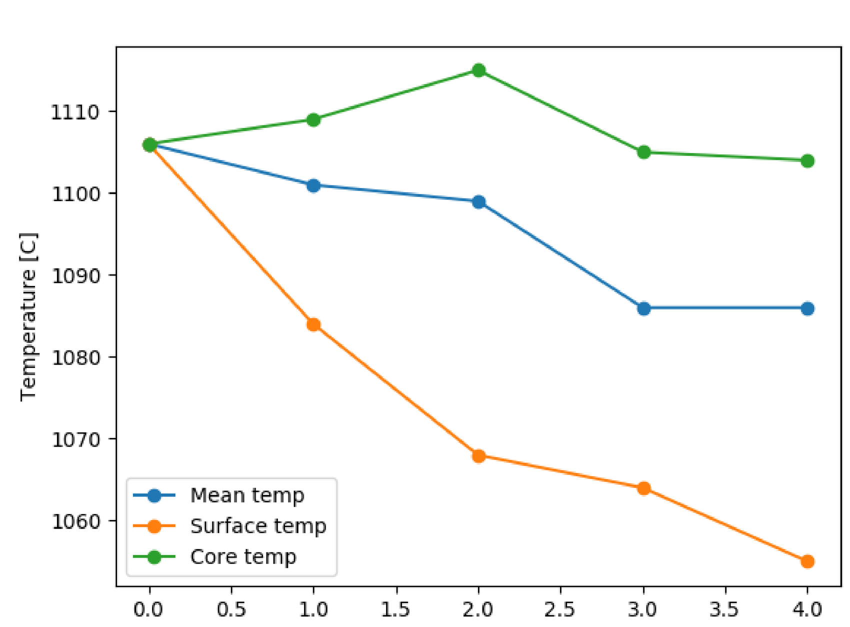
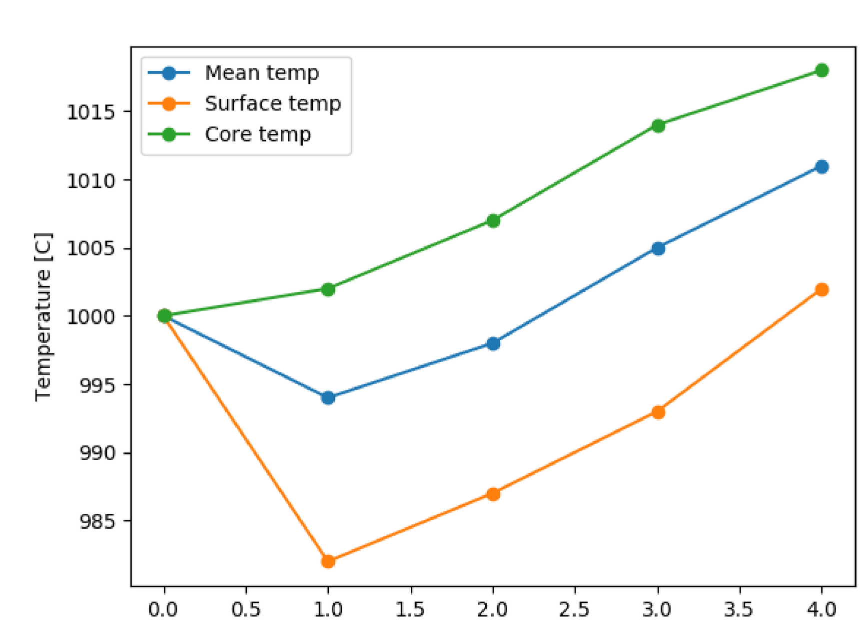
Discussion

- The deformation energy in this project was somewhat underestimated.
- For high speed wire rolling a coupled thermo-mechanical model is needed.
- To increase computational efficiency, a quarter of the domain can be used due to the symmetry of the solution.

Results





The left figure shows 330cb early in the line and the right figure shows 330cb at later stages when the dimensions are smaller.

In earlier rolling stages the distances between stands are longer and the speed of the material is slow. During this stage heat transfer has a large influence on the temperature. When the dimensions are small the deformation energy dominates the process. The added deformation energy diffuses inside the material before arriving at the next roller pair for the investigated cases.