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OpenFOAM model of fluid-structure interaction in dry wire drawing

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Dry wire drawing is a cold work hardening process, where a metallic wire is pulled through a series of dies, in order to progressively reduce its cross section. A sodium or calcium based soap lubricant is entrained by the wire into the die to reduce friction and the energy consumption. Moreover, this soap extends the service life of the die, as the surfaces of the wire and the die are separated by a thin lubricant film.

When modelling this process, the elastoplastic deformation of the wire needs to be considered, while the die is traditionally assumed rigid. The thin lubricant film is typically calculated using the Reynolds equation [1], which has a constant pressure-viscosity behaviour over the film thickness. As shown by [2], the Reynolds equation is only able to adequately capture the mechanics of piezo-viscous lubricants if $\boldsymbol{\tau\alpha < 1}$. In dry wire drawing, this condition is not satisfied as the shear stress $\boldsymbol{\tau}$ can obtain values higher than $\mathbf{10^8}\ \boldsymbol{Pa}$, whereas $\mathbf{10^{-8}}\ \boldsymbol{Pa^{-1}}$ is a conservative value of the pressure-viscosity coefficient $\boldsymbol{\alpha}$. Hence, the Navier-Stokes equations are used to more accurately capture the piezo-viscous behaviour of the soap by taking the cross-film pressure gradient into account.

This work presents a steady 2D axisymmetric Fluid-Structure Interaction (FSI) simulation of dry wire drawing, with the thin lubricant film determined from the Navier-Stokes equations and the deformation calculated by the structural equilibrium equations. The process is simulated with a strongly coupled partitioned approach. The coupling of the flow solver and structural solver is performed by the in-house code CoCoNuT using the quasi-Newton IQN-ILS technique [3]. Furthermore, the FSI in wire drawing demands a *sliding interface* between fluid and structure as the wire is moving axially through a fluid domain. A cell-centred finite volume discretization has been adopted, using pimpleFoam for the fluid and a Lagrangian solver in OpenFOAM-extend for the structural calculations [4]. The implementation of piezo-viscous behaviour of the lubricant is work in progress. The temperature effects and shear-thinning behaviour of the soap will be investigated in a later phase.

The die diameter decreases gradually during the simulation, until the required cross section reduction of the wire is achieved. Subsequently, a study of Cauchy stress and radial displacement of the structure is carried out. On the fluid side, the focus is on the behaviour of the pressure, traction and film thickness of the lubricant. Also drawing force and energy consumption are analysed.

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