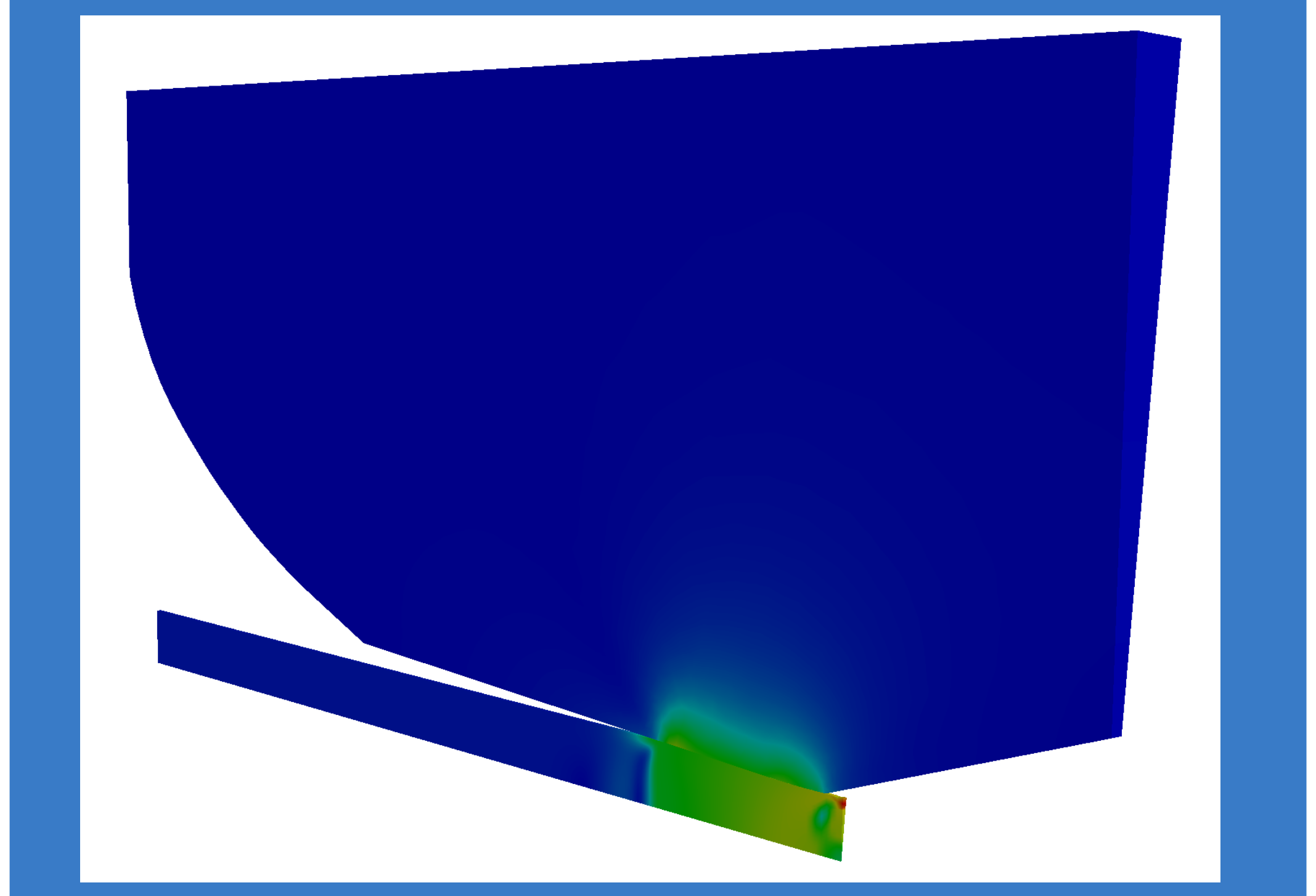
University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture
Department of Energy, Power Engineering and Environment

Lubricated Elasto-Plastic Contact Model for Metal Forming Processes

Vanja ŠKURIĆ
Peter DE JAEGER
Hrvoje JASAK



ABSTRACT

A numerical model for calculating lubricated contact pressures and friction in metal forming processes is presented in this study.

Several asperity contact models have been implemented, both with the elastic and elastic-perfectly plastic deformation of the asperities. A statistical principle of rough surface contact was utilized in this study.

The lubricant hydrodynamic pressure is calculated using the modified Reynolds equation in its compressible form which takes into account the roughness of surfaces in contact and cavitation effects.

The model is implemented as a solid contact boundary condition for a large strain hyperelastoplastic deformation solver developed by *Cardiff et al. (2016)* in `foam-extend`.

The model results are presented on a wire drawing case.

Introduction

Numerical model for calculating lubricated contact pressures and friction in cold metal rolling is presented in this study. Lubrication and friction are important factors in metal forming processes, since unoptimised frictional parameters can result in lower productivity of the process and deteriorate surface quality of the product. In order to capture frictional effects during lubricated metal forming simulations the presented numerical model was implemented as a boundary condition for a large strain hyperelastoplastic deformation solver developed by *Cardiff et al. (2016)* in `foam-extend`. The model takes into account surface roughness effects, different lubrication regimes and lubricant properties variations.

Mathematical Model

Lubricated contact between surfaces in relative motion can be divided into three regimes: hydrodynamic, mixed and boundary lubrication regime. In hydrodynamic regime two surfaces are completely separated by the lubricant. In mixed regime contact surface pressure is shared between asperities in contact and lubricant. In boundary lubrication regime major part of surface pressure is carried by asperities in contact.

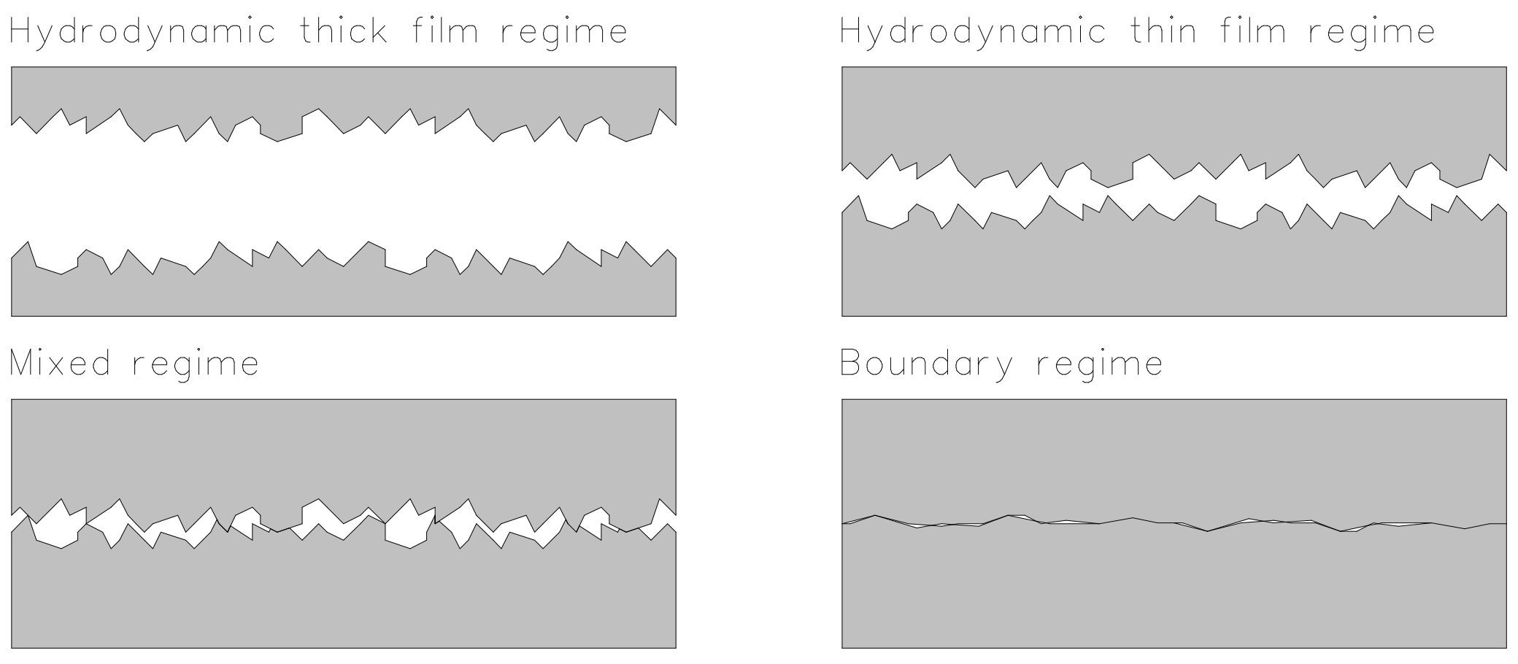


Figure 1: Lubrication regimes

In order to take into account all three lubrication regimes, total contact pressure P_n is divided into two parts: asperity contact pressure P_a and hydrodynamic pressure P_f.

$$P_n = AP_a + (1 - A)\,P_f,$$

where A is the ratio of asperity contact area to the unit nominal area. Correspondingly, shear traction P_t is defined by:

$$P_t = A\tau_a + (1 - A)\,\tau_f,$$

where τ_a is asperity traction and τ_f is lubricant shear stress.
In order to take into account material hardening of the asperities, simulations of a single asperity crushing were performed where contact forces and areas for different asperity interferences ω were calculated.
Total contact area and pressure of a two rough surfaces with surface mean distance d is calculated by integrating single asperity contact forces and areas for a range of asperities' heights z defined by the asperity height distribution $f(z)$:

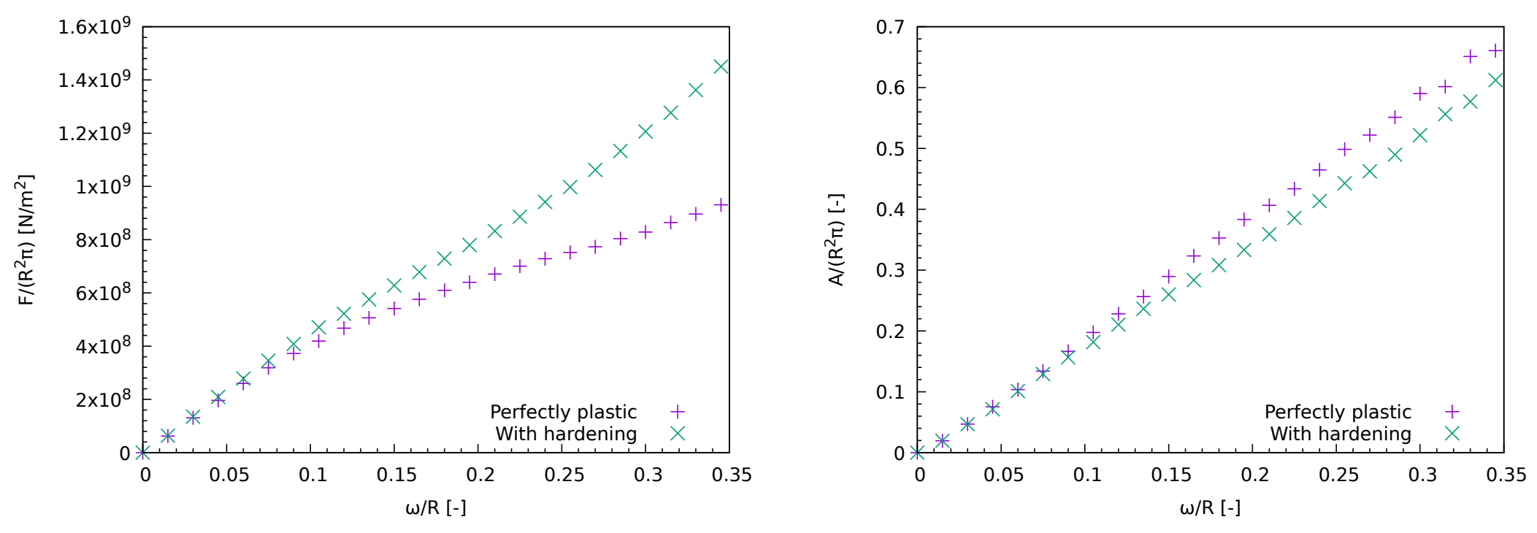


Figure 2: Comparison between elastic-perfectly plastic and elasto-plastic deformation with hardening effects of a spherical asperity

$$A(d) = \eta \int_d^\infty A'(\omega)\, f(z)\,\mathrm{d}z$$

$$P_a(d) = \eta \int_d^\infty F'(\omega)\, f(z)\,\mathrm{d}z$$

The lubricant hydrodynamic pressure is calculated using the modified Reynolds equation in its compressible form which takes into account the roughness of surfaces in contact and cavitation effects:

$$\nabla_s\bullet\left(\alpha\phi_{xy}\frac{\beta h_T^3}{12\mu}\nabla_s\rho\right) = \nabla_s\bullet\left[\frac{\rho h_T\left(\mathbf{U}_1+\mathbf{U}_2\right)}{2}\right] + \frac{\mathbf{U}_1-\mathbf{U}_2}{2}R_q\nabla_s\left(\phi_s\rho\right) + \frac{\partial\left(\rho h_T\right)}{\partial t}$$

where $\mathbf{U}_1$, $\mathbf{U}_2$ are tangential surface velocities of surfaces in contact, ρ is density, μ is dynamic viscosity, β is bulk modulus, h_T is the average film thickness, ϕ_{xy} and ϕ_s are pressure and shear flow factors, R_q is the composite surface roughness.

Wire Drawing

Film thickness and hydrodynamic pressure of lubricant during wire drawing process is presented.

Figure 3: Wire drawing contact detail

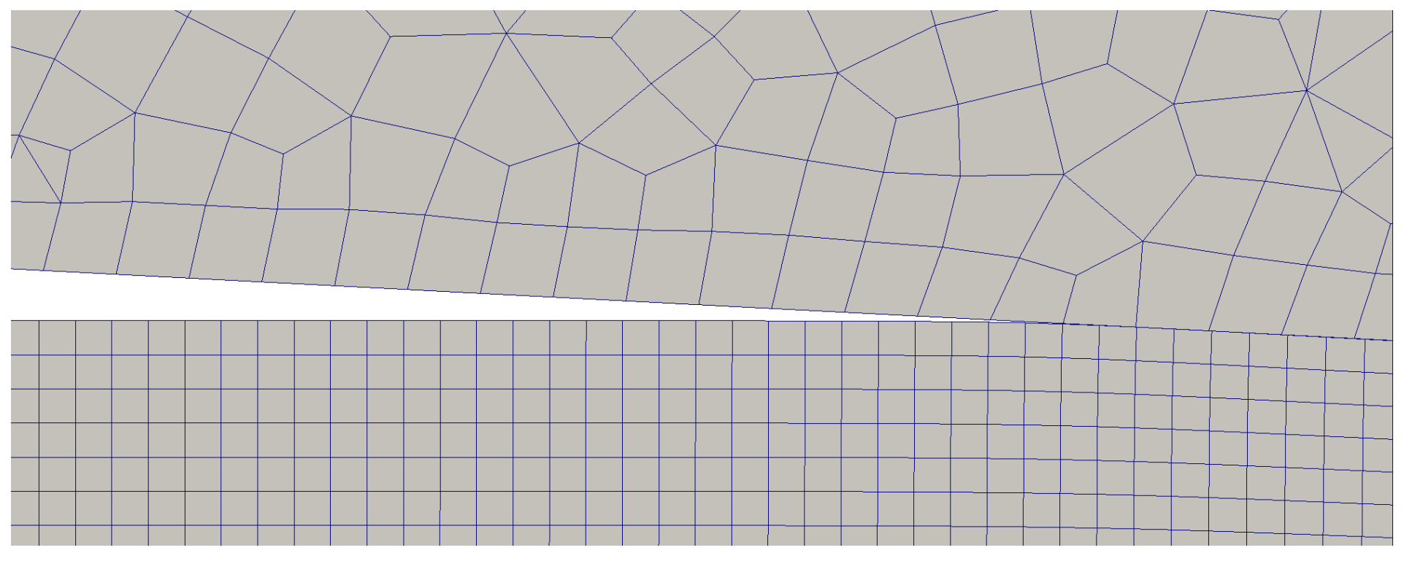
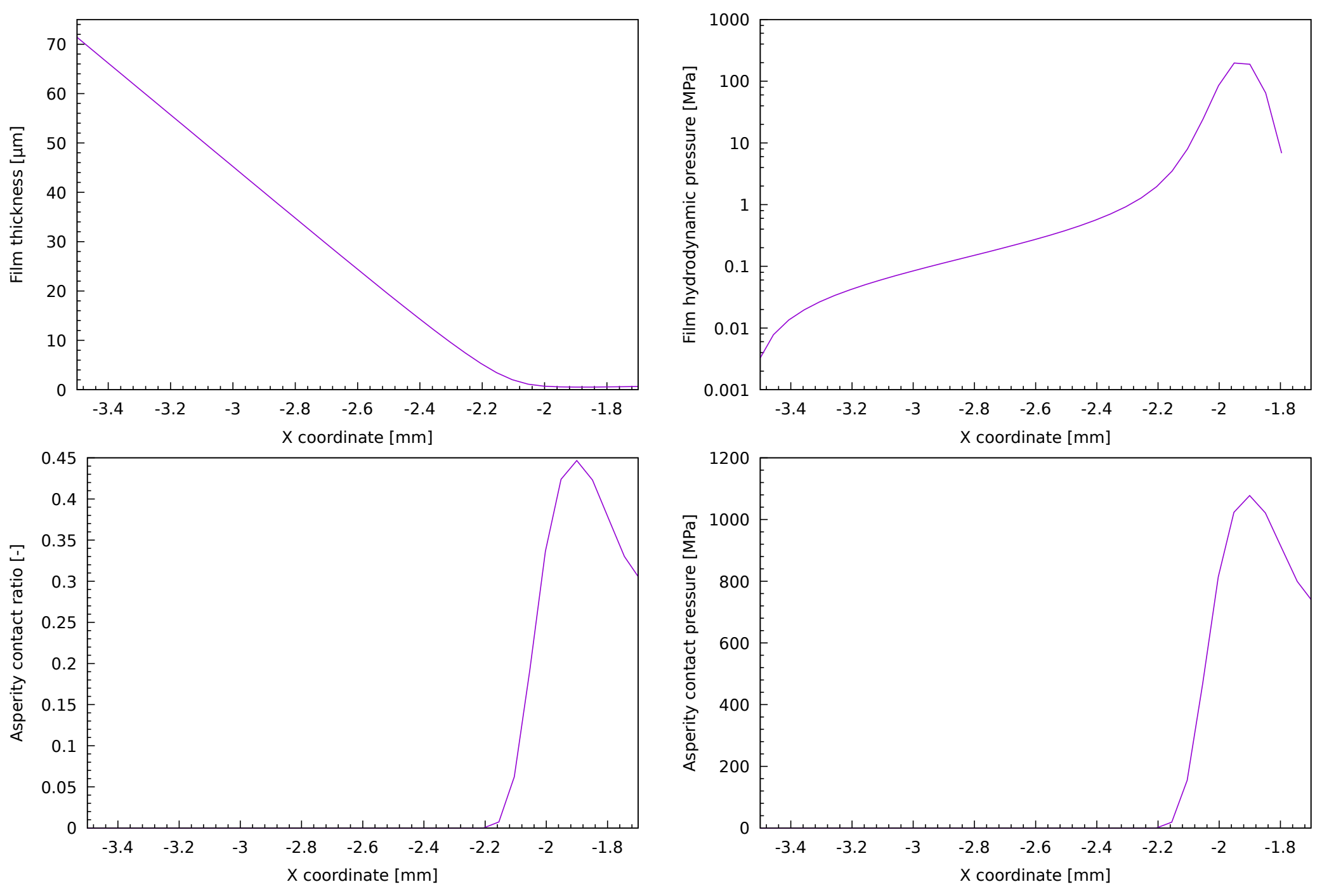


Figure 4: Lubricant film thickness and hydrodynamic pressure, asperity contact ratio and pressure in contact detail



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8th Floor CFD@FSB
www.fsb.hr/cfd

Feel free to contact us at vanja.skuric@fsb.hr or take a look at our YouTube channel: 8th Floor CFD@FSB.