PyRoll Hensel Roll Force and Torque Plugin

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This plugin provides the empirical roll force and roll torque models developed by A. Hensel and coworkers[1,2]. The models are empirical master curves dependent on the dimensionless parameter $A_\mathrm{d}/A_\mathrm{m}$, which is the ratio of contact area to the mean cross-section area of the profiles. It is called the roll gap ratio hereinafter. It is similar to the dimensionless parameters R/h_1 and $L_\mathrm{d}/h_\mathrm{m}$ often used in flat rolling.

Model Approaches used in the Plugin

Approach to roll force

The roll force is calculated by

$$F = \frac{k_\mathrm{Wm}}{k_\mathrm{fm}} \times k_\mathrm{fm} \times A_\mathrm{d}$$

where k_fm is the mean flow stress, A_d the contact area and k_Wm the deformation resistance. $k_\mathrm{Wm}/k_\mathrm{fm}$ is the inverse efficiency of the rolling process.

For the mean flow stress k_fm a weighted mean as below is used, since this provides a more suitable average than simple arithmetic mean. The indices 0 and 1 denote the entry resp. exit side as usual.

$$k_\mathrm{fm} = \frac{(k_\mathrm{f0} + 2k_\mathrm{f1})}{3}$$

The similar is the case for the mean cross-section A_m:

[1] Hensel, A., P. Poluchin, und W. Poluchin. Technologie der Metallformung. Deutscher Verlag für Grundstoffindustrie, 1990.

[2] Hensel, A., und T. Spittel. Kraft- und Arbeitsbedarf bildsamer Formgebungsverfahren. Deutscher Verlag für Grundstoffindustrie, 1978.

$$A_{\mathrm{m}} = \frac{(A_0 + 2A_1)}{3}$$

The value of $k_{\mathrm{Wm}}/k_{\mathrm{fm}}$ is obtained from the master curve in dependence on $A_{\mathrm{d}}/A_{\mathrm{m}}$ as shown in the figure. The figure shows accordingly several experimental measured values and the hull curves around all measurements. The red line is the weighted mean curve and is given by

$$\frac{k_{\mathrm{Wm}}}{k_{\mathrm{fm}}} = 0.9901 + 0.106\frac{A_{\mathrm{d}}}{A_{\mathrm{m}}} + 0.0283\left(\frac{A_{\mathrm{d}}}{A_{\mathrm{m}}}\right)^2 + 1.5718\exp\left[-2.4609\frac{A_{\mathrm{d}}}{A_{\mathrm{m}}}\right] + 0.3117\exp\left[-15.625\left(\frac{A_{\mathrm{d}}}{A_{\mathrm{m}}}\right)^2\right]$$

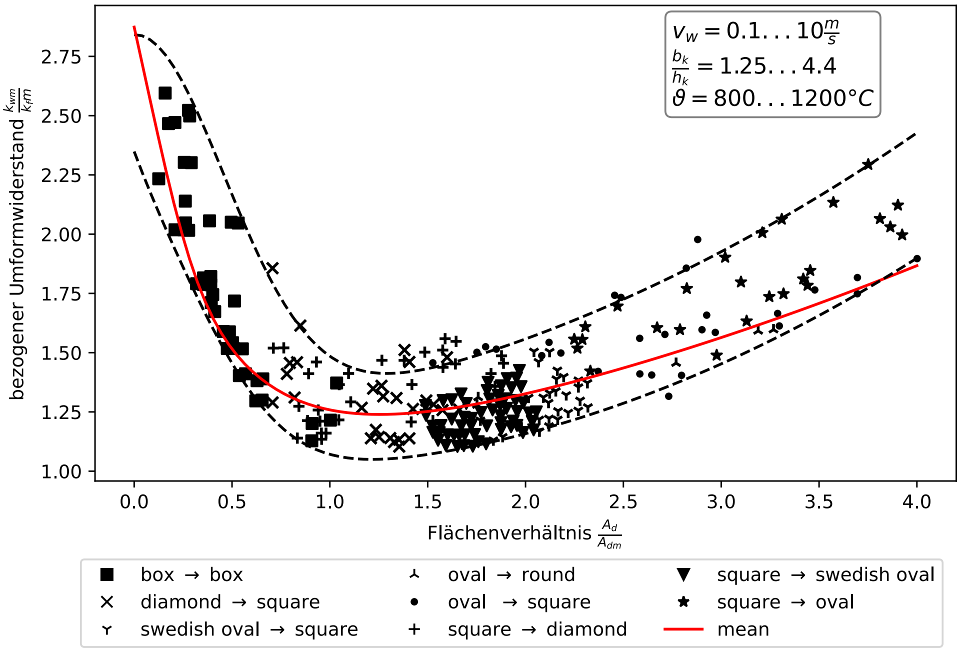

Figure 1: Hensel deformation resistance curve

Approach to roll torque

The roll torque is calculated by

$$M = F \times L_\mathrm{d} \times m$$

where L_d is the contact length and m is the lever arm coefficient.

The dependence of the lever arm coefficient on $A_\mathrm{d}/A_\mathrm{m}$ is shown in the figure with experimental data and their hull curves accordingly.

In additional dependence on the celsius workpiece temperature ϑ and rolling velocity v, m can be calculated by the following equation, as was implemented in the current case.

$$m = \left(\exp\left[-0.6\frac{A_\mathrm{d}}{A_\mathrm{m}}\right] + 0.076\frac{A_\mathrm{d}}{A_\mathrm{m}}\right) v^{0.005} \exp\left[-0.0003\left(\vartheta - 900\right)\right]$$

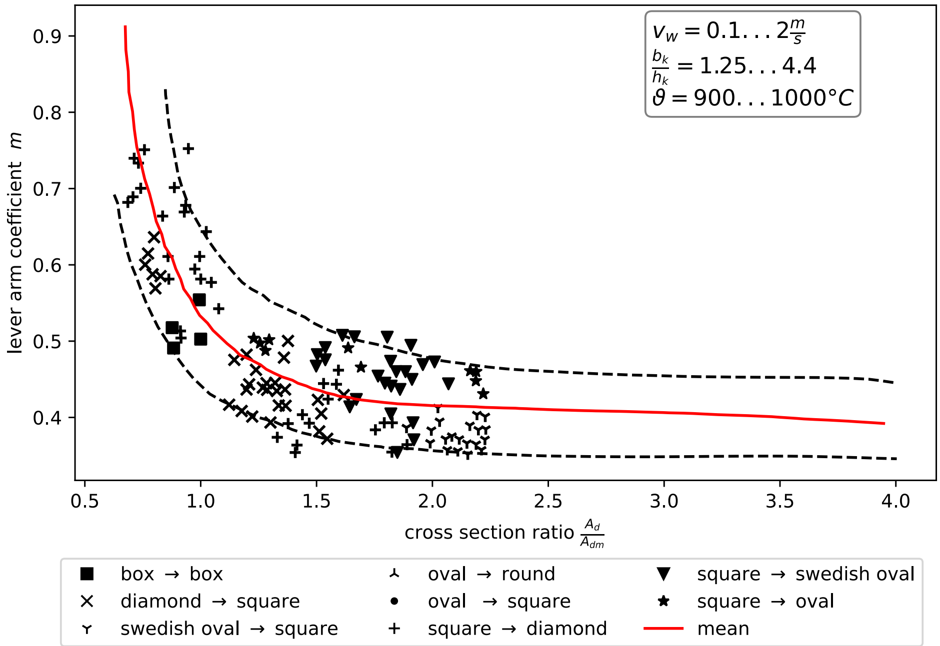

Figure 2: Hensel lever arm coefficient curve

Usage of the Plugin

The plugin provides implementations of the following core hooks:

`RollPass.roll_force` The roll force occurring in this pass calculated by the models described above. Uses the `RollPass.deformation_resistance` and `RollPass.contact_area` hooks.

`RollPass.Roll.roll_torque` The roll torque occurring in this pass calculated by the models described above. Uses the `RollPass.roll_force`, `RollPass.contact_length` and `RollPass.lever_arm_coefficient` hooks.

The following hooks are specified and implemented additionally:

`RollPass.roll_gap_ratio` The ratio of contact area to cross-section $A_\mathrm{d}/A_\mathrm{m}$. Uses the core hooks `Profile.cross_section` and `RollPass.contact_area`.

`RollPass.rolling_efficiency` The efficiency of the rolling process, that means the inverse of $k_\mathrm{Wm}/k_\mathrm{fm}$ obtained from the model shown above. Uses the `RollPass.roll_gap_ratio` hook.

`RollPass.deformation_resistance` The deformation resistance k_Wm calculated using $k_\mathrm{Wm}/k_\mathrm{fm}$ and the mean flow stress as described above. Uses the `RollPassProfile.flow_stress` and the `RollPass.rolling_efficiency` hooks.

`RollPass.lever_arm_coefficient` The lever arm coefficient m obtained from the model described above. Uses the `RollPass.roll_gap_ratio`, `RollPass.velocity` and `Profile.temperature` hooks.

One can modify the behavior of the plugin by providing constant attributes or custom implementations of the hooks. The plugin needs no additional material data or coefficients to be given on the initial profile or on the roll passes. Commonly it should work out of the box, without additional definitions by the user.