PyRolL Lee flow stress Plugin

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This plugin provides the implementation of the constitutive equation from Shida [1, 2] updated by Lee, Kim, Park, Seo, and Min [3] for higher strain rates to calculate the flow stress of low alloyed carbon steels.

1 Model approach

The model equation 1 was derived from flow stress measurements from Suzuki, Hashizume, Yabuki, Ichihara, and Satoshi [4] who investigated several low alloyed carbon steels.

$$k_f = \sigma_f f_\epsilon f_{\dot{\epsilon}} \tag{1}$$

From these measurements Shida [1, 2] derived his model equation which takes into account the strain ϵ, strain rate $\dot{\epsilon}$, absolute temperature T as well as the carbon content C of the material. The author showed that the model also works for low alloyed steels when replacing the carbon content which the equivalent carbon content $\bar{C}$. The model equation is valid for strains of up to 0.7, temperatures between 700 ° °C and 1200 ° °C and strain rates of $0.1\,\mathrm{s}^{-1}$ to $100\,\mathrm{s}^{-1}$. The maximum carbon content is 1.2 weight percent.

The focal point of the model is the normalized temperature $\bar{T}$ which is calculated using equation 2.

$$\bar{T} = \frac{T}{1000} \tag{2}$$

Further the author provides different variants of deformation resistance contribution σ_f, the strain contribution f_ϵ (see equation 3) as well as the strain rate contribution $f_{\dot{\epsilon}}$ (see equation 4) if the normalized temperature is greater or smaller than the phase transformation temperature T_p. The latter is calculated using equation 5. Lee, Kim, Park, Seo, and Min [3] altered the form of the strain rate contribution, to match higher strain rates which are typical when rolling in finishing blocks.

$$\begin{aligned} f_\epsilon &= 1.3 \left(\frac{\epsilon}{0.2} - 0.3 \frac{\epsilon}{0.2}\right)^n \\ n &= 0.41 - 0.07C \end{aligned} \tag{3}$$

$$f_{\dot{\epsilon}} = \left(\frac{\dot{\epsilon}}{10}\right)^{m} \left(\frac{\dot{\epsilon}}{100}\right)^{\frac{m}{2.4}} \left(\frac{\dot{\epsilon}}{1000}\right)^{\frac{m}{15}} \tag{4}$$

$$T_p = 0.95\frac{C + 0.41}{C + 0.32} \tag{5}$$

If the normalized temperature is above the phase transformation temperature the deformation resistance contribution as well as the exponent of the strain rate contribution are calculated using equations:

$$\begin{aligned} g(C,T) &= 1 \\ \sigma_f &= 0.28 * g(C,t) \exp\left(\frac{5}{\bar{T}} - \frac{0.01}{C + 0.05}\right) \\ m &= (-0.019C - 0.126)\bar{T} + (0.075C - 0.05) \end{aligned} \tag{6}$$

If the normalized temperature is below the phase transformation temperature the equations change to:

$$\begin{aligned} g(C,T) &= 30(C + 0.9) \exp\left(\bar{T} - 0.95\frac{C + 0.49}{C + 0.42}\right)^2 + \frac{C + 0.06}{C + 0.09} \\ \sigma_f &= 0.28 * g(C,t) \exp\left(\frac{C + 0.32}{0.19(C + 0.41)} - \frac{0.01}{C + 0.05}\right) \\ m &= (-0.081C - 0.154)\bar{T} + (-0.019C + 0.207) + \frac{0.027}{C + 0.320} \end{aligned} \tag{7}$$

2 Usage instructions

The plugin can be loaded under the name `pyroll_lee_flow_stress`. The plugin defines the hooks

Table 1: Hooks specified by this plugin.

Hook name	Meaning
`flow_stress`	Flow stress of the material
`flow_stress_function`	Flow stress as a function of the strain

References

[1] S. Shida. “Effect of Carbon Content , Temperature and Strain Rate on Compressive Flow-Stress of Carbon Stells”. In: *J. JSTP* 9.85 (1968).

[2] S. Shida. “Empirical Formula of Flow-Stress of Carbon Steels - Resistance to Deformation of Carbon Steels at Elevated Temperature - 2nd Report”. In: *J. JSTP* 10.103 (1969).

[3] Y Lee et al. "A Study for the Constitutive Equation of Carbon Steel Subjected to Large Strains, High Temperatures and High Strain Rates". In: *Journal of Materials Processing Technology* 130–131 (Dec. 2002), pp. 181–188. ISSN: 09240136. DOI: `10.1016/S0924-0136(02)00707-0`. (Visited on 04/21/2023).

[4] H. Suzuki et al. *Studies On The Flow Stress Of Metals And Alloys*. Tech. rep. 117. Tokyo: Institute of Industrial Science, 1968.