13.6. ADIABATIC ROLLING

In the analytical sections (13.2.1 and 13.2.2) the process of strip rolling was treated as an isothermal process. In reality the work of deformation and friction power are fully converted into heat. When heavy- or medium-gauge strip is rolled at high speeds, most of the heat absorbed by the strip does not escape the workpiece while it is in the roll gap. The strip in the roll gap heats almost adiabatically. Only after deformation is completed and the strip leaves the roll gap does cooling back to room temperature proceed.

The total power of deformation and friction losses per unit volume of rolled strip can be determined through Eq. (13.13) to be

$$w = \frac{2}{\sqrt{3}}\sigma_0\left[\ln\frac{t_0}{t_f} + \frac{1}{4}\sqrt{\frac{t_f}{R_0}}\sqrt{\frac{t_0}{t_f}-1} + \frac{m}{\sqrt{t_f/R_0}}\left(\sqrt{\frac{t_0}{t_f}-1} - \tan^{-1}\sqrt{\frac{t_0}{t_f}-1}\right)\right] \tag{13.51a}$$

Assuming that the total power of deformation of Eq. (13.51a) is generating adiabatic heating of the strip and that only the fraction k of the friction power is absorbed by the strip, Eq. (13.51a) becomes

$$w = \frac{2}{\sqrt{3}}\sigma_0\left[\ln\frac{t_0}{t_f} + \frac{1}{4}\sqrt{\frac{t_f}{R_0}}\sqrt{\frac{t_0}{t_f}-1} + \frac{mk}{\sqrt{t_f/R_0}}\left(\sqrt{\frac{t_0}{t_f}-1} - \tan^{-1}\sqrt{\frac{t_0}{t_f}-1}\right)\right] \tag{13.51b}$$

The temperature rise is then

$$\Delta T = \frac{w}{C} \tag{13.52}$$

where C is the specific heat of the strip. For the translation of specific heat from cal/g °C to kg cm/cm^3 °C see Eqs. (a) to (c) of Section 4.1.2. Some values of the specific heat are presented in Table 4.2.

The average temperature of the workpiece therefore is

$$T = T_{ave} = T_0 + \frac{\Delta T}{2} \tag{13.53}$$

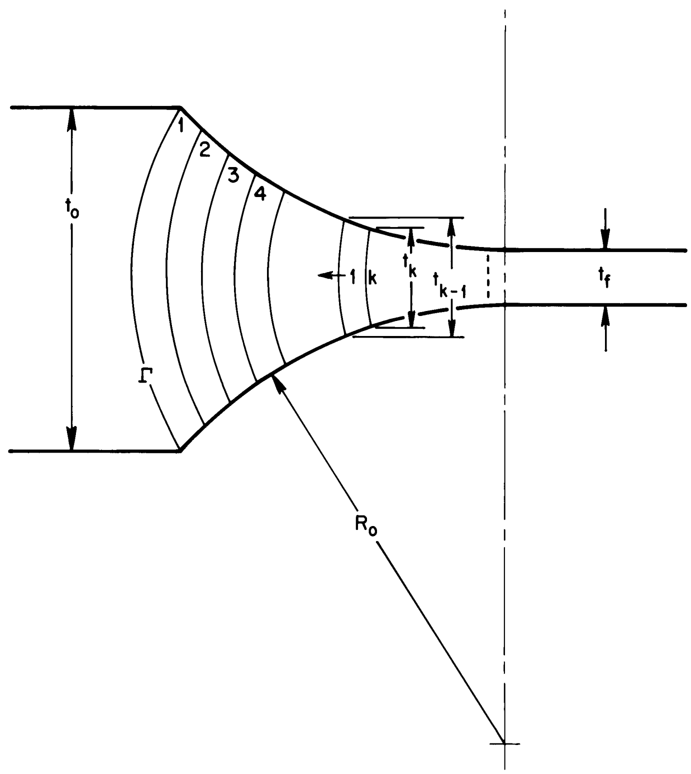

FIGURE 13.59. Division of the workpiece into regions.

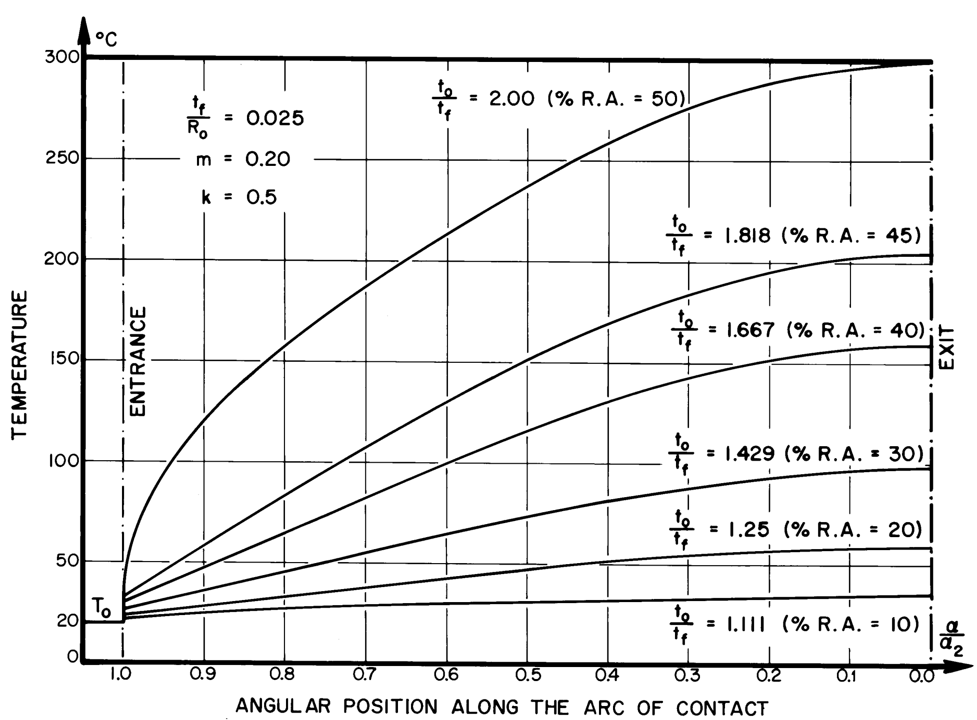

FIGURE 13.60. Profile of temperature from entrance to exit.

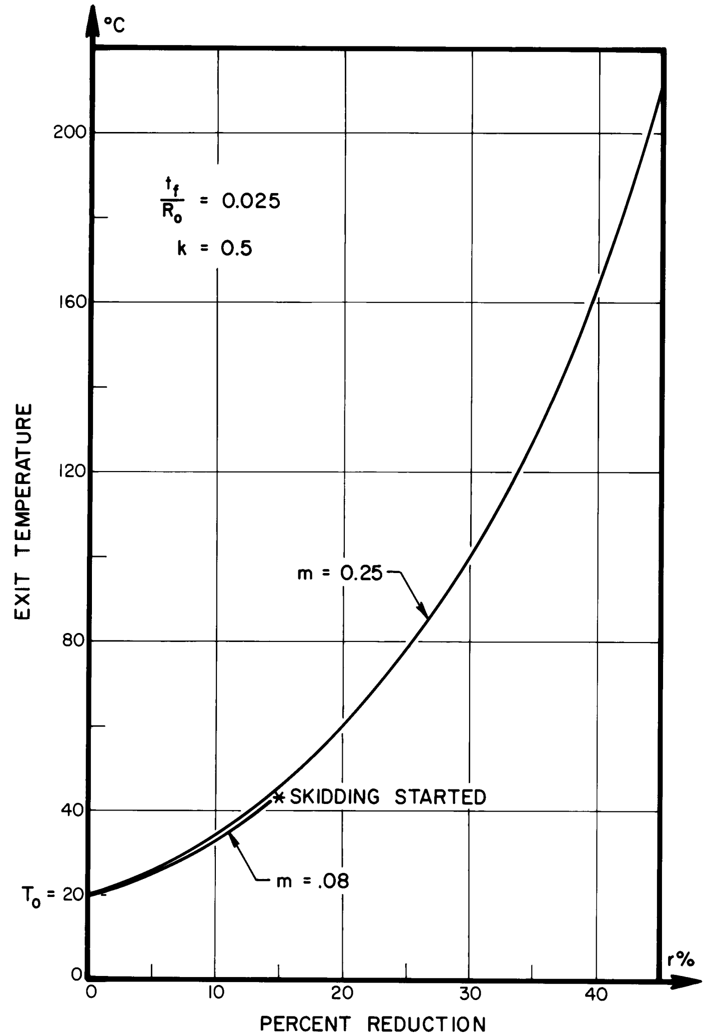

FIGURE 13.61. Temperature rise at the exit as a function of reduction and friction.

The strength σ_0 of the workpiece is a variable function of strain, strain rates and temperature. The functional relation is complex and not fully determined for any specific metal. In Ref. 58 [Eq. (2)] the simplifying assumption for this relation for steel was that

$$\sigma_0 \left[kg / cm^2 \right] = 250 \left(1 - \frac{T\left[^\circ C \right]}{1520} \right) \left(10 + A \tan^{-1} \phi \right) \tag{13.54}$$

where ϕ is the truth strain. Many other formulae are offered in the literature (e.g. Ref. 59) and can be easily incorporated by replacing Eq. (13.54).

In Eq. (13.54) it is assumed that the flow strength is not a function of the strain rate, which is true for steel below the recrystallization temperature. Furthermore, the flow strength is assumed to decline linearly with increasing temperature. The yield strength, given at zero effective strain ($\phi = 0$) and temperature 0 °C, is 2500 kg/cm^2. The ability to strain-harden is reflected through the constant A. When in Ref. 58 this was set at $A = 1$, the ultimate strength at infinite strain ($\phi = \infty$) was obtained as 2893 kg/cm^2. If $A = 8$ the ultimate strength becomes much higher, reaching 5640 kg/cm^2.

As the value of σ_0 changes with temperature, Eqs. (13.51)-(13.54) have to be solved simultaneously, or by successive approximations.

A study of strip rolling as an adiabatic process is presented in Ref. 60. There the strength of the strip was assumed to be that of Eq. (13.54) with $A = 1$. Furthermore, the strip was divided into small elements from the entrance toward the exit, as shown in Fig. 13.59. The temperature rise was computed at the surface of velocity discontinuity (Γ at $\alpha = \alpha_2$) as a temperature jump. (See Fig. 13.60.) Then, passing through small increments from entrance to exit, the temperature rise was computed for each element. In Ref. 60 the specific heat for steel was treated as a variable obeying the relations

$$C = 0.0397T + 32.22 \qquad for \qquad -100^0 C \le T \le 560^0 C \qquad (13.55)$$

The effect of reduction on temperature rise is shown in Fig. 13.60, while the effects of reduction and friction are shown in Fig. 13.61. The factor k in Figs. 13.60 and 13.61 denotes the fraction of frictional energy losses absorbed by the workpiece. The rest is absorbed by the rolls and the lubricant on the interface between the rolls and the strip.

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