

Modeling the Effect of Coating Weight on the Kinetics of Iron Enrichment in Hot Dip Galvanneal Coatings on Interstitial-Free Steel Sheets

C.R. Xavier, U.R. Seixas, and P.R. Rios

The coating weight is shown to have a significant effect on the isothermal kinetics of iron enrichment in hot dip galvanized coatings on interstitial-free (IF) steel sheets during a postcoating heat treatment that simulates galvannealing. A simple quantitative model is proposed to account for this effect and is found to give reasonable agreement with the experimental results obtained for the kinetics of iron enrichment for coating weights of 60 and 80 g/m^2.

Keywords galvannealing, hot dip galvanized, IF steels

A simple model for the kinetics of coating iron enrichment in hot dip galvanized interstitial-free (IF) steels for isothermal galvannealing has been recently developed (Ref 1, 2). The model has been shown (Ref 1-3) to give good agreement with Xavier, Seixas, and Rios (Ref 3), Jordan, Goggins, and Marder (Ref 4), and Lin, Meshii, and Cheng (Ref 5) data. A detailed description of the model as well as its assumptions and applicability can be found in previous work (Ref 1, 2). The fundamental equation of the model is:

$$\frac{dW}{dt} = k(W_S - W) \qquad \text{(Eq 1)}$$

where W is the coating iron content, W_S is a coating saturation iron content, and W_0 is the initial coating iron content, all in mass%. Equation 1 can be integrated noting that for $t = 0$, $W = W_0$, where W_0 is the initial coating iron content:

$$W = W_0 + (W_S - W_0)(1 - \exp(-kt)) \qquad \text{(Eq 2)}$$

In the present work, the above model is modified to take into account the effect of the coating thickness on the kinetics of iron enrichment of the Fe-Zn coating. This can be accomplished by applying mass-transfer concepts in the derivation of Eq 1. The flux of mass per unit of area into the coating can be written:

$$J = k_A(W_S - W) \qquad \text{(Eq 3)}$$

The mass of iron that flows through a certain area A of the interface between the steel and the coating must be equal to the increase in the mass of iron within the coating:

$$M\frac{dW}{dt} = AJ = Ak_A(W_S - W) \qquad \text{(Eq 4)}$$

where M is the total mass of the coating. Here one assumes that, as a first approximation, both the total mass of the coating, M, and the coating density remain constant. Noticing that M/A is the coating weight per unit of area, M_A, and that $W = 100\,(m/M_A)$ where m is the mass of iron per unit of area of the coating, Eq 4 can be written as:

$$\frac{dm}{dt} = \frac{k_A}{M_A}(m_S - m) \qquad \text{(Eq 5)}$$

Comparing Eq 1 and Eq 5 one can write:

$$k = \frac{k_A}{M_A} \qquad \text{(Eq 6a)}$$

$$W_S = 100\frac{m_S}{M_A} \qquad \text{(Eq 6b)}$$

where m_S is a certain saturation iron mass per unit of area of the coating. Integrating Eq 5 with $m = m_0$ at $t = 0$ gives:

$$m = m_0 + (m_S - m_0)\left(1 - \exp\left(-\frac{k_A t}{M_A}\right)\right) \qquad \text{(Eq 7)}$$

Table 1 Summary of parameters obtained by nonlinear curve fitting of Eq 7 to experimental data plotted in Fig. 2(a) to (c)

T (°C)	k_A (g/m^{2}s)	m_S (g/m^2)
450	5.60	6.17
500	5.84	8.39
550	6.63	9.64

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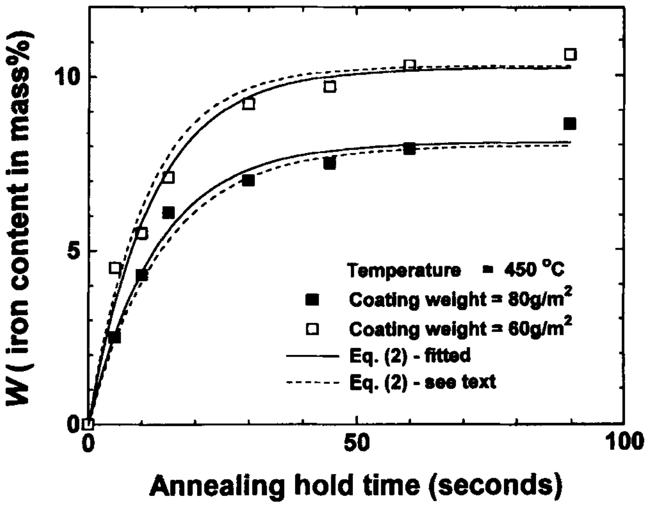
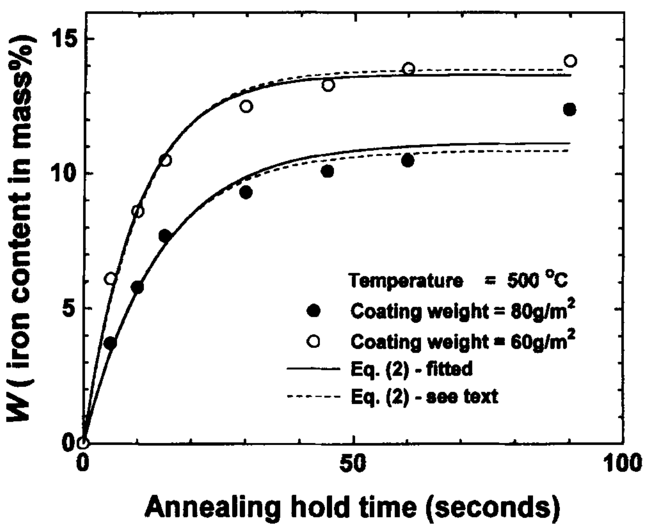


(a)



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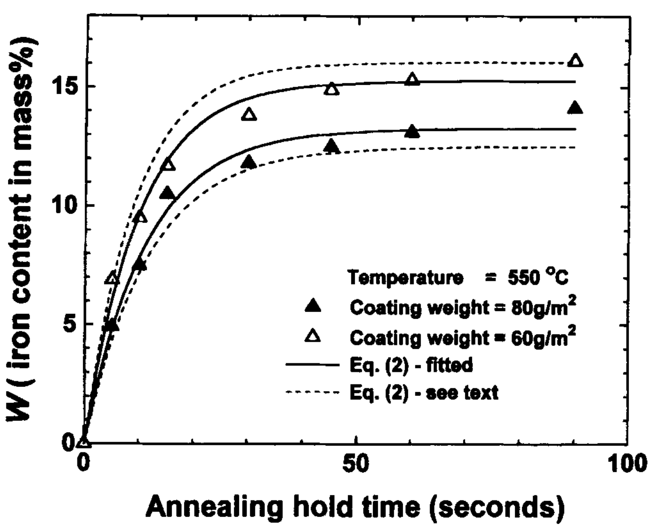
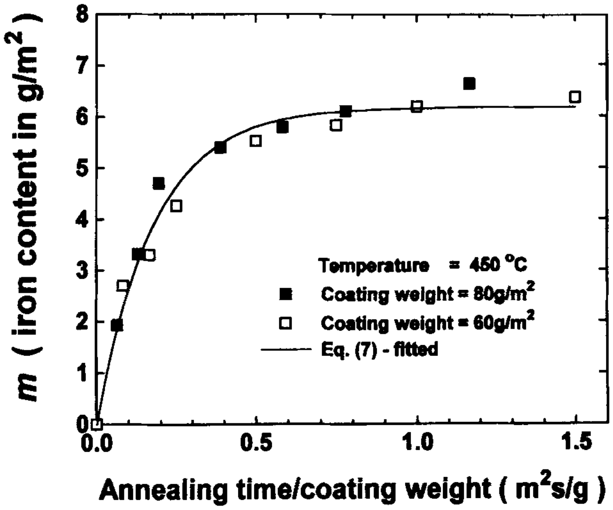
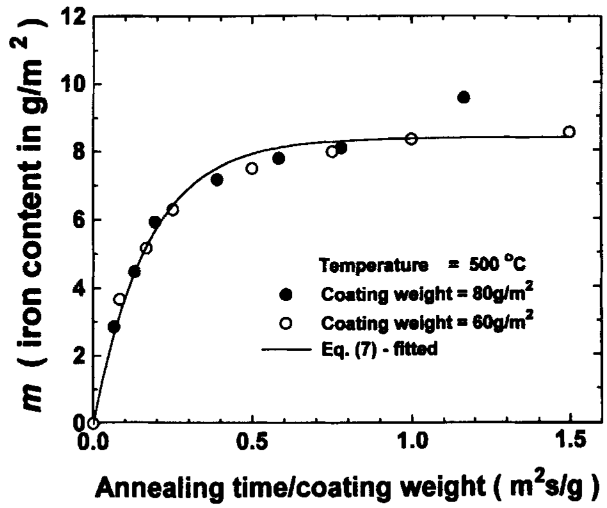


(c)

Fig. 1 *W*, coating iron content (mass%), as a function of annealing hold time(s) for annealing temperatures of: (a) 450 °C, (b) 500 °C, and (c) 550 °C. See text for explanation of the curves.



(a)



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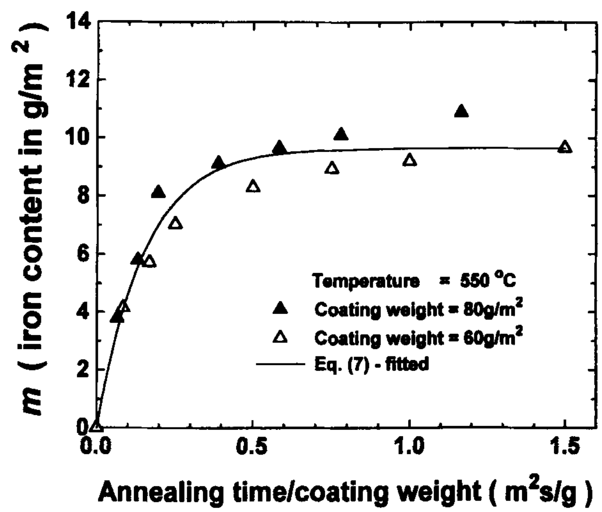

(c)

Fig. 2 *m*, coating iron content (g/m^2), as a function of annealing hold time(s) divided by coating weight (g/m^2) for annealing temperatures of: (a) 450 °C, (b) 500 °C, and (c) 550 °C. See text for explanation of the curves.

In order to study the effect of coating weight, a hot dip galvanized IF steel sheet with coating weight of 60 g/m^2 on one side and 80 g/m^2 (77.1 g/m^2) on the other was used. The substrate chemical composition (mass%) was as follows: carbon, 0.005; manganese, 0.16; phosphorus, 0.007; sulfur, 0.008; silicon, 0.016; titanium, 0.089; nitrogen, 0.003; aluminum, 0.091; iron, balance. Specimens measuring 100 × 100 mm were annealed in a salt bath at 450, 500, and 550 °C for holding times ranging from 5 to 90 s and water quenched. The heating rate was about 40 °C/s, and the annealing times were measured from the instant the specimen reached the required temperature. From the center of the specimens, 60 mm diam disks were taken for the determination of the mass% of iron in the coating. This was done separately on each side of the disk using a sulfuric acid solution to dissolve the coating. The aluminum content of the zinc bath was high, 0.20 mass% (nominal), so the amount of iron initially present in the coating was very low.

The results are shown in Fig. 1(a) to (c) in which W, the coating iron content in mass%, is plotted against annealing hold time for annealing temperatures of 450, 500, and 550 °C, respectively. It can be seen that the kinetics of iron enrichment is significantly faster for the 60 g/m^2 coating compared to that of the 80 g/m^2 coating. The solid lines in Fig. 1(a) to (c) were obtained by nonlinear least squares fitting of Eq 2 to the experimental data. W_0 was taken to be equal to 0. Equation 2 is in good agreement with experimental data. A summary of the fitted parameters, k and W_S, can be found in a previous work (Ref 3).

Figures 2(a) to (c) show the data in Fig. 1(a) to (c) replotted as m against t/M_A. The values of m were obtained from measured W values by $m = M_A(W/100)$ with M_A taken as the coating weight of the as-galvanized sheet. The solid lines in Fig. 2(a) to (c) were determined by nonlinear least squares fitting of Eq 7 to the experimental data. It can be seen that Eq 7 gives good agreement with the data for the lower annealing temperatures: 450 and 500 °C (Fig. 2a and b), and somewhat worse but still fair agreement with the data for the highest temperature: 550 °C (Fig. 2c). This latter result might be a consequence of assuming a constant M_A that might not be such a good approximation for the higher levels of iron enrichment obtained at 550 °C. A summary of the fitted parameters, k_A and m_S, can be found in Table 1.

In order to check the consistency of the model, one may use k_A and m_S obtained by Eq 7 to calculate k and W_S for each coating by means of Eq 6(a) and (b). These calculated values of k and W_S were inserted into Eq 2. The resulting curves are plotted as dashed lines in Fig. 1(a) to (c). It can be seen that the dashed lines are in good agreement with the solid lines and the experimental data for 450 and 500 °C (Fig. 1a and b), but the agreement is somewhat worse for 550 °C (Fig. 1c). This behavior reflects the worse agreement observed in Fig. 2(c). On the whole, the agreement is reasonable, particularly when one considers the simplicity of the model.

In summary, the kinetics of iron enrichment are significantly faster for lower coating weights. Moreover, the simple model presented here can satisfactorily describe this effect.

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