

# Comments on “Bainite formation kinetics in high carbon alloyed steel”

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## Abstract

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We examine here the physical aspects and input parameters of a recently published model on the overall transformation kinetics of the bainite reaction in steels.

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A kinetic model for the development of bainite in steels has recently been published which purports to be physically based and uses only two fitting parameters [1]. The purpose of this note is to explore this further.

The kinetic equation apparently based on Avrami theory [2–4], is an adapted version quoted from [5] who claim that the general form is:

$$f = 1 - \exp\{-b(t - t_0)^n\} \quad (1)$$

where  $f$  is the fraction of transformation,  $b$  and  $n$  are constants and  $t_0$  is the “incubation time” which is measured experimentally. This is in fact a mistake because  $t_0$  is incorrectly taken to be the incubation time detected in an overall transformation measurement [5]. Avrami theory does not lead to the term  $t_0$  in the equation for  $f$ , but deals instead with an incubation time  $\tau$  for each particle.

It is important to emphasise the difference between  $t_0$  and  $\tau$ . The former is the time corresponding to an arbitrary detectable volume fraction of transformation and hence depends on the precision of the measuring technique.  $\tau$  is the time at which a particular particle comes into existence;  $\tau$  does not explicitly appear in the Avrami equation; once established, the latter permits  $t_0$  to be *calculated* in a manner consistent with the detection limit of the experimental technique used.

This mistake regarding  $t_0$  is carried through in equation 5 of [1] and means that  $t_0$  is an additional fitting parameter for *each* isothermal experiment; the three  $t_0$  values needed in [1] are presumably from the experimental data in their Fig. 1.

In conducting the analysis to find the fitting parameter  $K_2$  in order to make an empirical adjustment to the activation energy for nucleation, the form of the Avrami type equation used is correctly stated as  $f = 1 - \exp\{-k\{T\}t^n\}$  with  $n = 2$ , which is inconsistent with their equation 5 which has the term  $(t - t_0)^2$ .

The growth rate equation used is based on the work of Bosze and Trivedi [6] for the diffusion-controlled growth of parabolic cylinders (plates). The solution leads to a constant lengthening rate but parabolic thickening. Therefore, the volume of a particle in the absence of soft-impingement must vary with  $(t - \tau) \times (t - \tau) \times (t - \tau)^{\frac{1}{2}}$ . Given the assumed constant nucleation rate, this would lead to  $n = 3\frac{1}{2}$  and not the 2 assumed in [1]. Notice that  $k\{T\}$  in the nucleation rate analysis is said to be proportional to the product of the nucleation rate and the lengthening rate  $\dot{N}_\alpha \times v_{0\alpha}$ , but this assumes only one-dimensional growth. Plates actually grow in three dimensions.

Further fitting parameters include  $v'$  the so-called deviation from the maximum growth rate, the nucleation site density and interfacial energy and the cross-section of the bainite plate which is known to vary with temperature [7].

In summary, it is difficult to accept that this model has predictive capabilities [8] but it may be useful in the quantitative description of known experimental data.

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