Reply to the Letter to the Editor

Regarding the Paper "Stable Eutectoid Transformation in Nodular Cast Iron: Modeling and Validation"*

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In the discussion of the article,[1] J. Lacaze exposes that in continuous cooling of nodular cast irons, ferrite can nucleate but cannot grow during the intercritical stable eutectoid. Related to this statement, there are two considerations that could give rise to alternative approaches for the problem under discussion: (i) the possible redistribution of C in austenite during continuous cooling (and the corresponding to substitutional elements, if any, not considered in Reference 1) and local Si content (inherited from solidification), and (ii) the thermodynamic constraints related to ferrite nucleation. Both aspects would decide whether or not ferrite can nucleate during this intercritical range, and subsequently growth or not.

The graphics presented by Lacaze in Figures 2 and 3 only consider two points which correspond at equilibrium of carbon and silicon concentrations at the austenite/ferrite and ferrite/austenite interfaces. The model presented in the article under discussion[1] considers equilibrium only at interfaces. In the bulk, there is no reason to consider that carbon and silicon concentration are the same that equilibrium carbon and silicon concentration at interphases. If we assume that the carbon and silicon concentration in austenite (not only at austenite/ferrite interface) are the same that equilibrium concentration values, the authors agree with Lacaze proposal. But it is not the case that concerns the article under discussion.

Why ferrite can grow during the intercritical stable eutectoid? In order to answer this question, the author of this letter considers that the bulk composition should be taken into account.

(a) The C percentage in austenite away from ferrite: at the end of the solidification, the percentage of C in austenite can be considered equal to the equilibrium C concentration in austenite in contact with graphite (point Ex in Figure 1 of Reference 2). From the end of the solidification to the start of the stable eutectoid transformation, the nodules grow at expenses of the C diffusion from the austenite away from the graphite, it should be pointed out that:

- It is not possible to consider that the percentage of C in the austenite away from the graphite nodules is equal to the equilibrium C concentration in austenite in contact with the graphite (see Figure 3 of Reference 3).
- The depletion of C in austenite far from the austenite/graphite interface will be low, recognizing that the growth of the nodules at this stage is negligible.

All in all, in continuous cooling processes, there is no reason to consider that the C percentage in austenite away from ferrite equals to the equilibrium C content in the austenite/graphite and austenite/ferrite interfaces at the lower limit of intercritical stable eutectoid range.

(b) The Si percentage in austenite away from ferrite: on the other hand, a deeper analysis is necessary for the change in Si concentration. Most of the authors, but the ones indicated in References 4 and 5, propose that in SGI the solid-state phase transformations occur without partition of substitutional elements. Consequently, the microsegregation profiles developed during the solidification are retained after solid-state phase transformations.

In Figure 1, the profiles of Si and Mn between two graphite nodules are shown. They correspond to the spheroidal cast iron employed in the paper under discussion. There, the concentration of Si is over 3 wt pct for an extension of approximately more than 10 μm. This accumulation of Si in front of graphite nodules has its origin in the low solubility of Si in graphite. In consequence during the nodule growth, Si is stacked in the liquid ahead of the graphite. Therefore, when the temperature of the alloy reaches the value corresponding to the upper limit of intercritical stable eutectoid region, the austenite away from ferrite would present enough accumulation of Si to justify the possible growth of ferrite without Si partition.

Having the adequate percentages of C and Si necessary for the ferrite growth under continuous cooling conditions, how is it possible that in some cases ferrite

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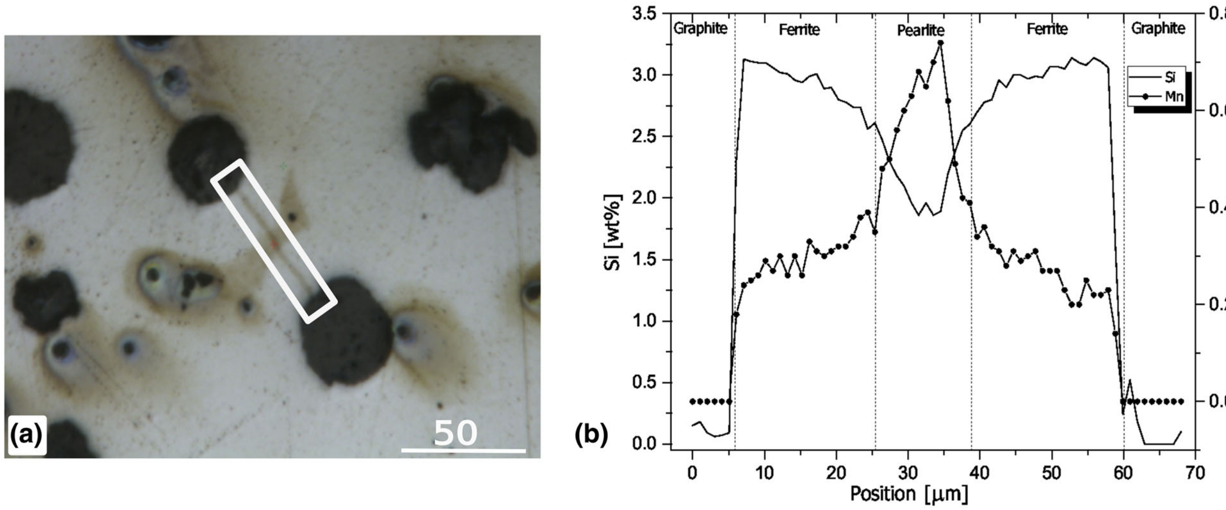

Fig. 1—(*a*) Micrograph with indication of Si and Mn path measurement, and (*b*) distribution of Si and Mn wt. pct across the path indicated in (a).

does not grow when the temperature reaches the upper limit of the stable eutectoid? The analysis of the CCT curves presented in References 6 and 7 can answer this question: by the extrapolation of the starting curve of the austenite to ferrite transformation at 1084K (811 °C), it can be checked that the time required for the transformation to begin cannot be accomplished by most of the continuous cooling processes in practice—in the experiment considered in our publication, the cooling rate is approximately 60 K/minute.

In the approach proposed by J. Lacaze, he only considers the equilibrium carbon and silicon concentrations at ferrite/austenite and austenite/ferrite interphases. For the model proposed by the author of the article under discussion, it is a crucial point to consider the bulk composition in order to establish the mechanism that controls stable eutectoid transformation in the intercritical stable eutectoid range, and not only the equilibrium carbon and silicon concentrations at interphases. This represents a difference between the model under discussion and the explanation proposed by J. Lacaze. On the other hand, the limitation in the kinetics of the austenite to ferrite transformation during the intercritical stable eutectoid, could be associated with a limitation in the available time for incubation before nucleation takes place.

In addition, classifying the ferritic transformation as a process developing under local equilibrium conditions for all the elements present in the alloy (with or without partition of alloying elements), or as a process taking place under para-equilibrium condition, requires carrying out complementary studies to the ones already presented by Lacaze in his letter.

To sum up, ferrite growth during stable eutectoid intercritic is an open point which requires a wider study which should contemplate tracing substitutional element profiles at the interface of the austenite/ferrite interphase and understanding the influence of the alloying elements as a function of their influence in the C activity in austenite prior to the transformation.

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