Comment on "The Precipitation of Carbides during Tempering of High Carbon Martensite*"

(Received February 21, 1972)

Ohmori and Sugisawa are to be congratulated on producing such a detailed and comprehensive investigation of the complexities of carbide formation in tempered steels⁽¹⁾.

However a close study of this paper reveals several inconsistencies which we regard as important. These are detailed below.

First, in Photo. 5, the diffraction pattern (c) is indexed in (d) as two zones of epsilon carbide precipitated in martensite. In the text it is stated that the orientation relationship deduced from this diffraction pattern is that proposed by Jack⁽²⁾, yet the diffraction pattern itself indicates an orientation relationship nearer to that of Doi and Nishiyama⁽³⁾. This is interesting as Murphy and Whiteman found the non-symmetrical Jack orientation relationship on tempering a silicon steel⁽⁴⁾.

The authors do not state whether the epsilon carbide growth direction was $\langle 211 \rangle_\alpha$ as reported in⁽⁴⁾. This would be a particularly interesting piece of information in view of the conflicting reports produced by different investigators⁽⁴⁾⁻⁽⁶⁾.

Second, the authors claim to have identified χ -carbide as a product of tempering in their steels. Murphy et al. recently completed an exhaustive study of the tempering process and concluded that χ -carbide is not formed at any stage in carbon steels⁽⁷⁾. Since χ -carbide was characterised by Senateur and Fruchart⁽⁸⁾ it has been recognised that cementite and χ -carbide are very similar in structure, the difference arising in the stacking of the layers of prisms of iron atoms. Hence single crystal electron diffraction patterns may be obtained which could be indexed as either χ -carbide or cementite, both showing the expected orientation relationship with the matrix. As it has also been shown that in the early stages of tempering the interplanar spacings of the cementite may be altered both intrinsically and by coherency stresses⁽⁷⁾, unambiguous interpretation of diffraction patterns is often not possible. Cementite is known to exist in tempered steels, therefore all ambiguous patterns must be indexed as cementite until such time as χ -carbide is proved to exist in these steels. In our view only if the normal to the $(100)_\chi$ planes is incorporated, can single crystal diffraction patterns be regarded as positive proof of the existence of χ -carbide.

Fig. 1 Stereogram showing the cementite zone corresponding to the diffraction pattern of Photo. 9.

Fig. 2 Expected diffraction pattern deduced from Fig. 1.

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Fig. 3 (a) Diffraction pattern from cementite in Isaichev orientation relationship.
(b) Indexing of the diffraction pattern.

Our diffraction results have always shown that from the first appearance of third-stage carbide as very thin layers, the cell dimension normal to the prism layers was that of cementite rather than χ -carbide.

Photograph 9 in the paper is not a diffraction pattern from χ -carbide. The diffraction spots are from cementite in the Isaichev orientation relationship with the iron matrix. The plane of the foil lies on the great circle drawn on the stereogram of Fig. 1, and the predicted diffraction pattern is shown in Fig. 2. Note that the net of Photo. 9 (c) is only apparent, not real, and that this apparent net is not truly continuous across the whole diffraction pattern. The lateral displacement of the apparent net is in fact clearly visible in Photo. 9 (c) of the paper.

One must conclude that the authors have not presented evidence for the existence of χ -carbide as a tempering product, as claimed.

Finally to the question of the orientation relationship of cementite in tempered martensite. This has been

determined as that of Isaichev rather than that of Bagaryatskii⁽⁷⁾, the difference amounting to a rotation of $3^{\circ} 38'$ about the $[010]_{\text{cem}}$. This rotation places only one set of the most closely packed planes in cementite, say the $(103)_{\text{cem}}$, parallel to the most closely packed planes in martensite, say the $(101)_{\alpha}$.

The difference between the Isaichev and Bagaryatskii orientation relationships is clearest in the $\langle 010 \rangle_{\text{cem}}$ zone. A diffraction pattern showing such a zone is shown in Fig. 3 (a) and its indexing in Fig. 3 (b). This pattern was obtained from a 0.5% C, 25% Ni steel with subzero M_s , quenched, cooled in liquid N_2 and tempered at 135°C . Even at this temperature cementite has formed on the twin planes of the martensite. It is evident that the cementite is in the Isaichev orientation relationship with the martensitic matrix in which it has formed.

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