Title

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ON THE ORIENTATION RELATIONSHIPS BETWEEN RETAINED AUSTENITE AND "LATH" MARTENSITE

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Recent careful analysis of steels by transmission electron microscopy in our laboratory[1-3] has shown that it is possible to resolve stabilized interlath films of retained austenite in some carbon containing steels transformed to "lath" martensite. These results were unexpected particularly in view of the fact that the bulk M_s and M_f temperatures of these steels are above room temperature.[3,4] Several mechanisms for stabilization of austenite in these steels were subsequently proposed[5,3] and it was shown[4] that the presence of interstitial carbon is a necessary condition for retention of austenite at room temperature. Ever since its discovery, considerable work[2,3,6] has been directed towards the influence of this retained austenite on the mechanical behavior of the steel although very little attention was paid to the crystallography and mechanism of lath martensite formation in the light of these new observations. In this communication, some observations made on the orientation relationships of the austenite → lath martensite transformation will be reported.

Of the four possible orientation relations between fcc austenite and bcc martensite[7] viz., Bain, Pitsch, Nishiyama-Wasserman (N-W) and Kurdjumov-Sachs (K-S), only K-S and N-W relations are widely reported.

The K-S and N-W relations are related simply by a 5.26° rotation around the normal of a close packed plane in either crystal structure, Fig. 1. In several instances these orientation relations were obtained from high carbon, high alloy steels wherein twinned plate martensite forms from parent austenite during quenching to room temperature.[7] Due to the inability of earlier investigators to resolve retained austenite in steels transformed to lath martensite, these investigators had to rely on indirect methods of arriving at the orientation relations from the observed martensite crystal (lath) orientations. The underlying assumption in all the earlier work is that the orientation relationship between retained austenite and lath martensite is unique in a given steel. However, the present results show that the orientation relationship is not always unique. Fig. 2 shows the most frequently observed indexed selected area diffraction pattern obtained from lath bundles and the interlath austenite in a medium carbon Fe-4%Cr-0.3%C steel. Figs. 3(a) and 3(b) show the morphology of lath martensite and retained austenite in bright-field and dark-field modes respectively in a Fe-4Cr-0.3C-2 Mn steel. The corresponding indexed selected area diffraction pattern is shown in Fig. 3(c). The highly symmetric electron diffraction pattern of Fig. 2 allows reasonably accurate determination of crystal orientations. In Fig. 2, there are two martensite zones $[100]_\alpha$ and $[111]_\alpha$, and yet a single $[110]_\gamma$ zone.* Considering only one martensite crystal variant at a time, the $[111]_\alpha$ and $[110]_\gamma$ combination results in the K-S relation, Fig. 4(a), but if $[100]_\alpha$ and $[110]_\gamma$ are considered, the result is the N-W relation, Fig. 4(b). It is clear, therefore, that this is an ambiguous pattern for orientation relationship analysis although this was not recognized by other workers.[6,8,9] The particular combination of orientations, viz.,

*The subscripts α and M refer to martensite and the subscripts γ and A refer to austenite.

$[<100>_\alpha$, $<111>_\alpha$ and $<110>_\gamma]$ has been observed very frequently in the present investigation.[5] Similarly, the $<100>_\alpha$ and $<111>_\alpha$ combination of orientations were observed to occur quite extensively by several past investigators.[8,9] In the absence of retained austenite reflections, the resulting diffraction pattern corresponding to Fig. 2 would be as depicted in Fig. 4(c) consisting only of the $[111]_\alpha$ and $[100]_\alpha$ zones. This has led previous investigators[8] to misinterpret the two martensite orientations as the result of adaptation of two different variants of K-S relation in adjacent laths of a packet. However, Nemirovskiy and Nemirovskiy[9] showed recently that the particular combination of martensite lath orientations, viz., $<111>_\alpha$ and $<100>_\alpha$, can not be shown to correspond to two different variants of the K-S relation. These investigators, in an effort to find an unique, single orientation relationship, concluded[9] that the deviation of the experimentally observable orientation of martensite crystals from calculations in accordance with the K-S orientation relation is due to each martensite crystal orientation rotated through $\sim 2.6°$ round the normal to the close packed planes (Fig. 1) which enter the orientation relation. On this basis, they concluded that the actual orientation relationship is exactly intermediate between K-S and N-W. This conclusion can not be disproved as long as only matrix martensite reflections are recorded, Fig. 4(c). However, the present investigation using direct evidence of retained austenite reflections, Fig. 2, has shown that what is in fact happening is that both K-S and N-W orientation relationships are alternating within the same packet and that the orientation relationship between a particular martensite crystal (lath) and parent austenite is either K-S or N-W but not intermediate (see Fig. 5 schematic). In the present study, evidence for the K-S relation as the dominant orientation relationship in the ternary Fe-Cr-C steels is obtained from several other unambiguous diffraction patterns.[1-5] The addition of either Mn or Ni to these ternary Fe-Cr-C alloys changes the dominant orientation relationship to N-W, as shown in Fig. 3(c). In this figure, although there are again two martensite orientations, viz., $[110]_\alpha$ and $[311]_\alpha$ and a single austenite orientation, $[21\bar{1}]_\gamma$, it can be shown that neither of the martix orientations belongs to a K-S variant. The $[1\bar{1}0]_\alpha$ and $[3\bar{1}1]_\alpha$ crystal directions in this figure are not exactly twin related but rotated $\sim 6°$ about $[\bar{1}10]_\gamma$ direction.[10] It has been pointed out[10,9] that the appearance of twin orientations of martensite crystals is evidence that the orientation relationship during $\gamma \to \alpha$ transformation is very close to the precise K-S relation. Twin orientations of martensite crystals corresponding to the different variants of an orientation relationship are analytically impossible for any N-W relation.

In summary, the present study involving direct crystallographic analysis using retained austenite has revealed that the dominant austenite-martensite (lath) orientation relation in medium carbon experimental steels corresponds to either K-S or N-W depending on the composition. These observations do not support earlier predictions for an orientation relation which is exactly intermediate between K-S and N-W relations. More significantly, it is identified in this study that austenite/martensite phases can obey both K-S and N-W orientation relations alternatingly amongst the martensite laths of the same packet (Fig. 5). There is no a priori reason why this can not happen. On the other hand, a hypothesis can be advanced to explain this on the basis that the two orientation relations give better flexibility in terms of increased variants available during martensite nucleation.[4,5] In addition, these observations point out the extreme cautions to be exercised in the use of indirect methods of crystallographic analysis for lath martensite transformation which also probably accounts for the wide scatter[4,8] in the habit plane analysis of this technologically important transformation.

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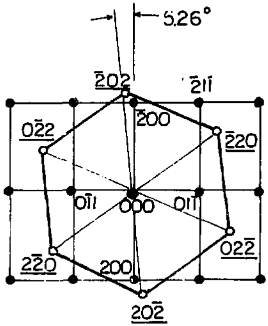
FIGURE CAPTIONS

1. Calculated composite austenite-martensite diffraction patterns revealing the relatively simple correspondence between the K-S and N-W orientation relationships between fcc austenite and bcc martensite.
2. Most frequently observed selected area diffraction pattern consisting of two martensite zones $[111]_{\alpha}$ and $[100]_{\alpha}$ and a single austenite zone, $[110]_{\gamma}$ in the as-quenced structures of many medium carbon steels.
3. (a), (b), (c): BF, DF and SAD pattern respectively showing retained austenite in Fe-4Cr-0.3C-5Ni alloy. DF (b) is obtained using $(02\bar{2})_{\gamma}$ reflection of the $[211]_{\gamma}$ zone. N-W orientation relationship is shown in (c).
4. (a), (b), (c): Detailed analysis of diffraction pattern corresponding to Fig. 2.
5. Schematic showing the obeyance of both K-S and N-W orientation relations within the same lath martensite packet corresponding to the diffraction pattern of Fig. 2.

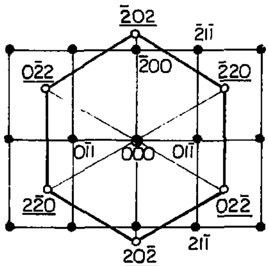


K-S ORIENTATION RELATION:

$(011)_{bcc} // (111)_{fcc}$

$[\bar{1}1\bar{1}]_{bcc} // [\bar{1}10]_{fcc}$

● hkℓ bcc
○ <u>hkℓ</u> fcc



N-W ORIENTATION RELATION

$(011)_{bcc} // (111)_{fcc}$

$[100]_{bcc} // [10\bar{1}]_{fcc}$

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Fig. 1

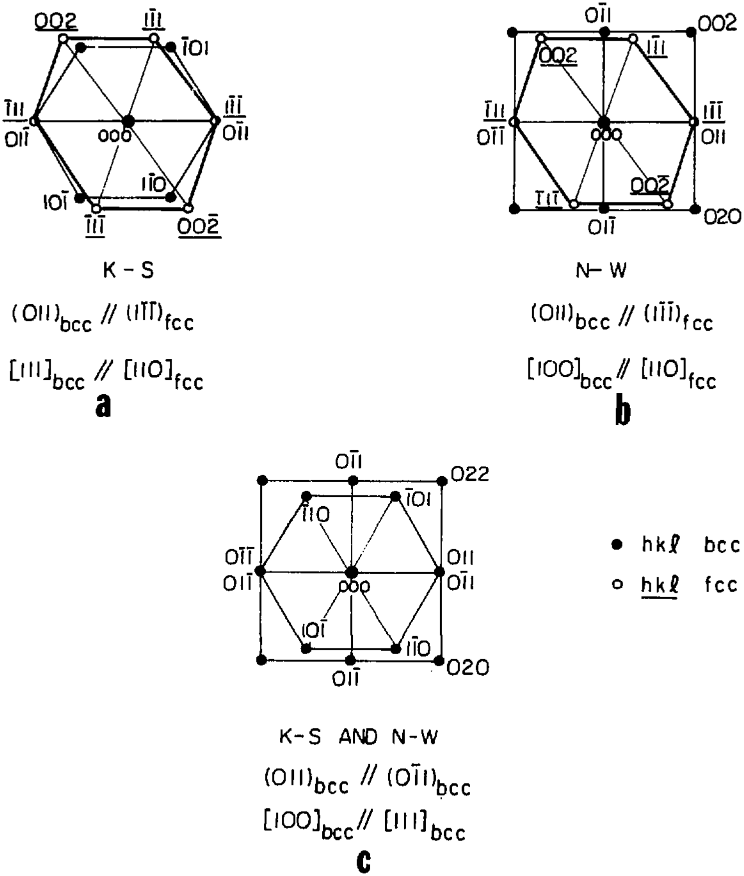

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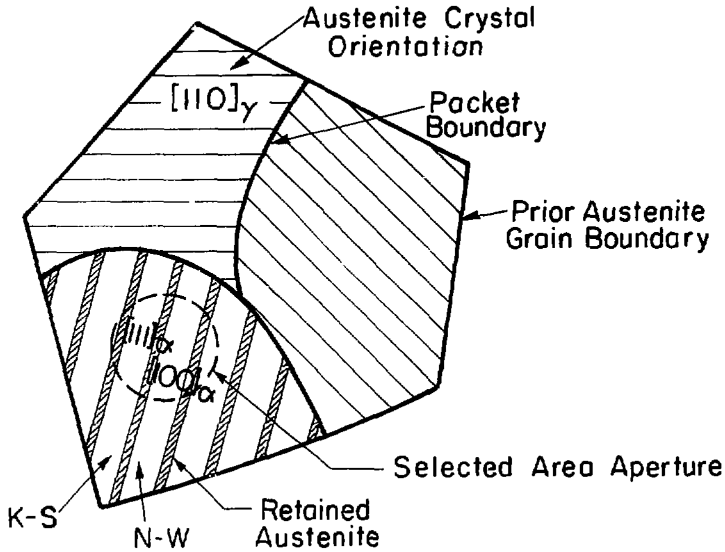
Fig. 4

Dislocated Lath Martensite



XBL 786-5209

Fiq. 5