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# ON THE MORPHOLOGY AND SUBSTRUCTURE OF MARTENSITE

S. Das and G. Thomas

Inorganic Materials Research Division, Lawrence Radiation Laboratory,
and Department of Materials Science and Engineering,
College of Engineering, University of California,
Berkeley, California

In iron-nickel and iron-carbon alloys two different morphologies of martensite have been well recognized. In Fe-C steels up to ~0.3%C and in Fe-Ni alloys up to about 28 wt % nickel the martensite consists of groups of laths. The laths within each group are separated by low angle boundaries and one group of laths may be separated from another by a high angle boundary. The martensite of this type has been called massive martensite,[1] lath martensite,[2,3] needle-like martensite[4] and is known to be dislocated. In high carbon* or high nickel alloys acicular or plate-like martensite is seen which is internally twinned. So far, no evidence of internal twinning in lath martensite has been reported in the literature. Recently, Ansell et al.[5] indicated that there were internal twins in a needle-like martensite formed after very high quench rates in 0.50%C steel. In this report direct evidence of {112} internal twinning in such a martensite is presented. The steels investigated are basically 9Ni-0.24C, one with no cobalt, and the other with 7% cobalt.

Figure 1 shows an example of transformation twins in the laths in the 9Ni-0.24C alloy. The presence of twins was verified in the usual way from diffraction pattern identification and by dark field imaging

*However, small amounts of internally twinned plates are observed even in 0.14%C alloys.

of twin spots. Also, the fact that the laths in a group are separated by low angle boundaries is shown from the observed single bcc orientation of a number of laths [Fig. 1(b)], and the dark field micrograph of a matrix spot which reversed contrast for adjacent laths. Fine transformation twins in some of the relatively narrow laths is seen in Fig. 2. The twins appear to be lenticular and their width varies from 100 to 700Å. Such small twins in laths look very much like fine carbides in lower bainite laths and can be often misinterpreted unless properly identified. Similar twins are also seen in the cobalt containing alloy [Fig. 3]. The fact that additions of cobalt do not reduce twinning has been pointed out earlier.[6]

These results show that the inhomogeneous shear in massive or lath martensite need not be always slip. Thus, it is not necessarily a condition that twinning is always associated with a martensite which is plate-like (see Wayman[7]). It follows that the morphology of martensite, i.e., plate-like or lath-like does not depend on the substructure, i.e., whether twins are present or not.[8] Thus, the classification of ferrous martensites into lath and twinned, as adopted by many workers,[2,3] is not very appropriate and a further distinction between twinned and dislocated laths is necessary.

Thus, one should use metallographic descriptions with caution. All we really can say is that there are two types of martensite: dislocated martensite (e.g., in low carbon steels) and twinned martensite.

A recent investigation[6] of a series of Fe-Ni-Co-C steels has shown that the martensites in alloys with the same Ms temperatures may have widely different amounts of twinning, and so the Ms temperature alone is not a sufficient indication of internal twinning. From a comparison of Fe-C and Fe-N martensites Bell and Owen[9] suggested that the transition from a dislocated to a twinned martensite may occur when a critical driving force of the martensitic transformation ($\Delta G$) of about 315 cal mole$^{-1}$ is expected. Pascover and Radcliffe[10] extended this concept to Fe-Ni and Fe-Cr systems and found that in Fe-Ni system the critical driving force is about 300 to 370 cal mole$^{-1}$ at 29 at % Ni, where actually the substructural transition is observed. In the Fe-5 Wt % Cr alloy although their computed driving force was between 300 and 350 cal mole$^{-1}$, they did not observe any twinning in the martensite. Thus, in addition to the effect of composition on the driving force, it is also necessary to consider its effect on the critical resolved shear stress for twinning and slip. If the CRSS for twinning is less than that for slip at the temperature where martensite forms, it will twin as discussed by Johari and Thomas.[11] If the driving force is enough and the CRSS for twinning is lower than that for slip, twinned martensite is expected irrespective of its morphology (i.e., lath or plate). The absence of twinning in Fe-5% Cr alloy,[10] even though a high driving force exists, may thus be explained on the basis that the CRSS for twinning is higher than that for slip at the transformation temperature.

ACKNOWLEDGMENT

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## FIGURE CAPTIONS

Fig. 1 (a) Bright field micrograph of martensite in 9Ni-0.24C steel showing internal twins inside the laths.

(b) Selected area diffraction of the encircled area in (a), with matrix in ~[122]. Twinning on $(12\bar{1})$ plane and then on $(11\bar{2})$ plane brings a $(\bar{1}10)$ twin reflection at $\frac{1}{3}(\bar{4}11)_{matrix}$ position and a $(\bar{1}\bar{1}\bar{4})_{twin}$ reflection at $(03\bar{3})$ matrix position. The other extra spots are due to double diffraction.

(c) Dark field micrograph of $(\bar{1}10)$ twin reflection showing reversal of contrast for twins.

(d) Dark field micrograph of $(01\bar{1})$ matrix reflection. There is no twin spot coincident with $(01\bar{1})$ matrix.

Fig. 2 Another group of relatively narrower laths than Fig. 1, showing fine internal twins.

Fig. 3 Internal twins in lath martensite in 9Ni-7Co-0.24C steel.

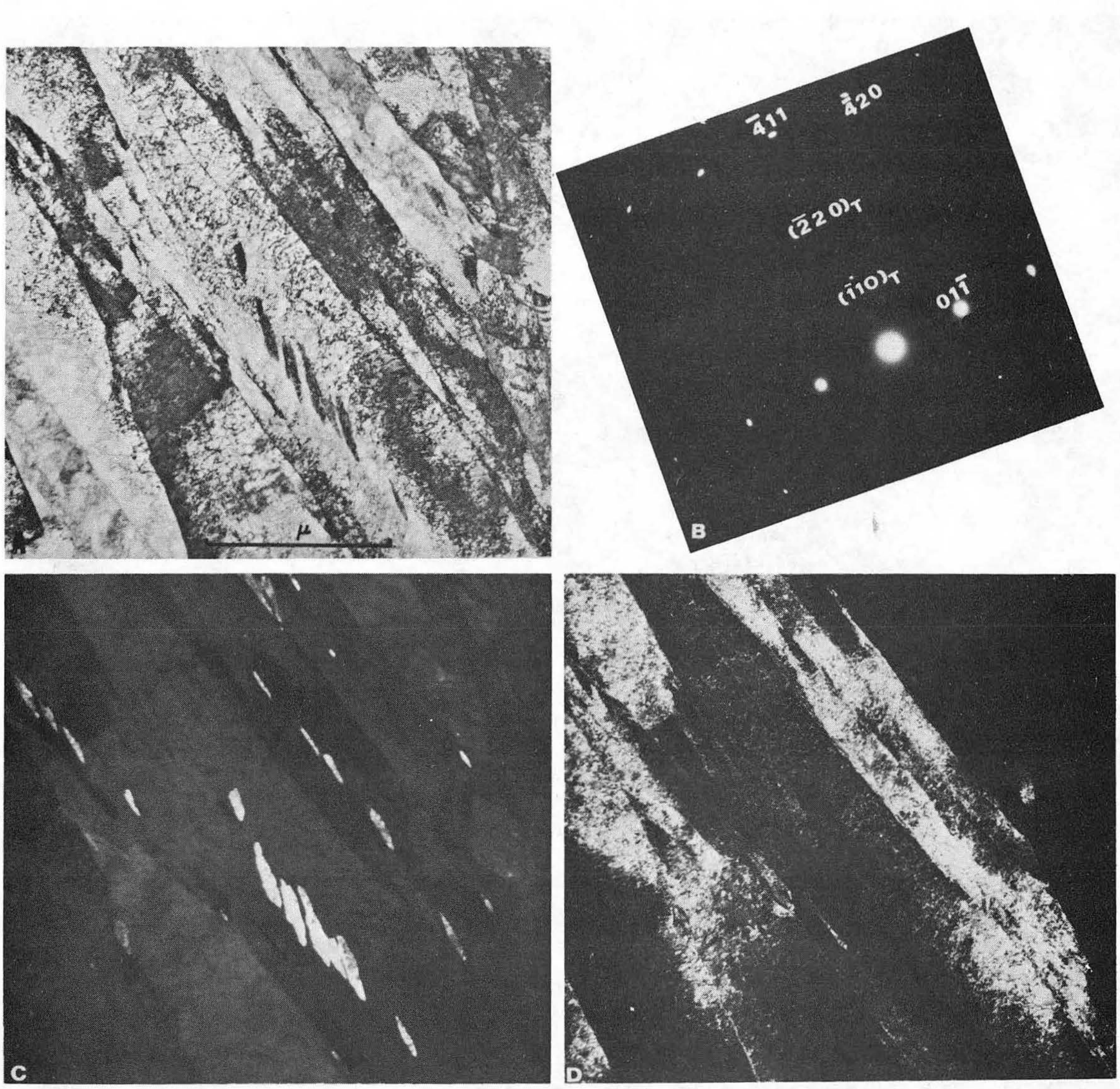


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Fig. 1

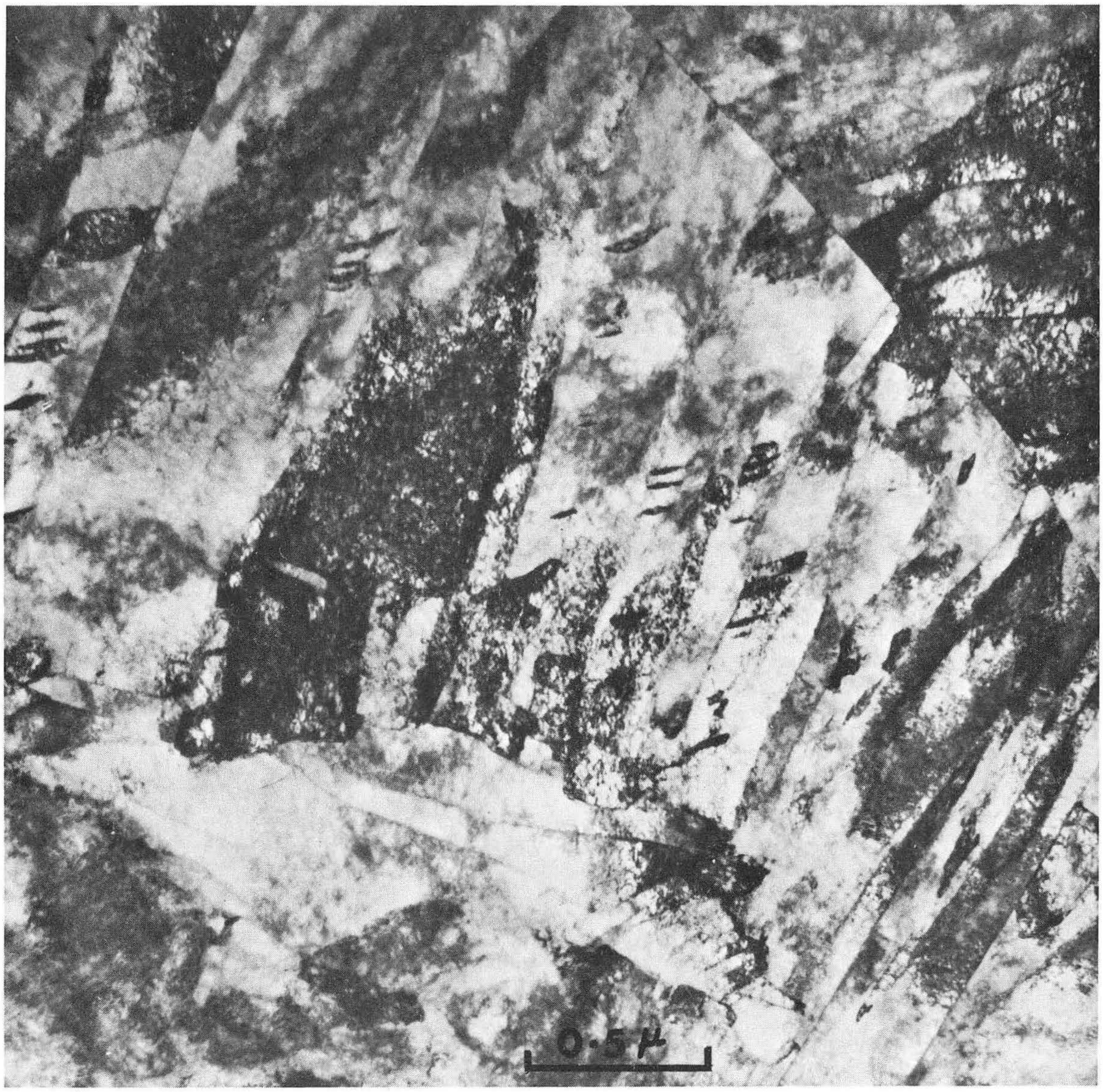


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Fig. 2

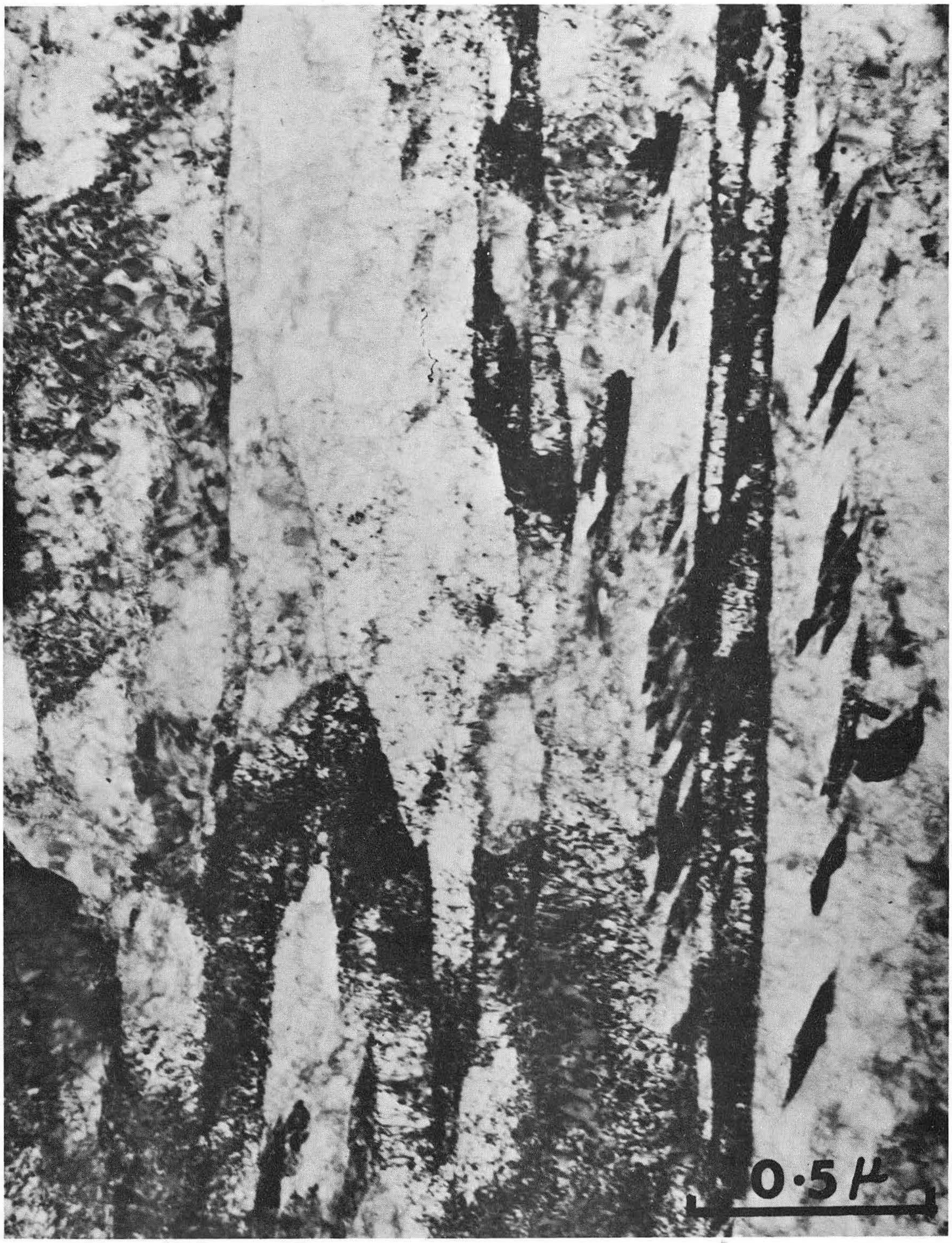


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Fig. 3

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UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720