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The microstructure of as-quenched 12Mn steel

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A R T I C L E I N F O

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A B S T R A C T

Fe-12Mn steel has the unique and interesting property that, when quenched to α' martensite from the austenite phase, it forms an ultrafine grained microstructure that has exceptional resistance to cleavage fracture at cryogenic temperatures. The present research was undertaken to complete the characterization of this microstructure and understand why it forms and why it has such exceptional crack resistance. A combination of EBSD and TEM analysis shows that the microstructure is a dislocated lath martensite in which the laths have the Kurdjumov-Sachs relation to the parent austenite. As in other dislocated lath martensites, the prior austenite grains are divided into packets, each of which contains the 6 (of 24) KS variants that mate with the same $\{111\}_\gamma$ plane. Uniquely, however, the packets are stacks of thin plates that contain all 6 KS variants. The variants within the plate are organized into 3 pair of twinned KS variants that are elongated along their $\{112\}_\alpha$ twin planes, rotated 120° from one another, and interwoven to form the 6-variant plate. The ultrafine grains are the laths themselves; twin boundaries between KS variants are known to provide strong barriers to cleavage crack propagation. This unusual microstructure is apparently due to the transformation path; austenite transforms to the hexagonal ε martensite phase before its ultimate transformation to α', and the 6-variant plate is the preferred element to minimize elastic energy in a microstructure created by a dominant $\gamma \rightarrow \varepsilon \rightarrow \alpha'$ transformation path.

1. Introduction

Fe-Mn binary alloys with content near 12Mn have one of the most interesting, and potentially useful microstructures found in martensitic steels [1,2]. When quenched from the FCC γ-phase, Fe-12Mn alloys transform into an ultra-fine grained martensite of columnar laths that are less than 1 μm in diameter and 2–3 μm in length (Fig. 1(a)). Moreover, adjacent laths are crystallographically distinct with the consequence that the effective grain size (the "block" size of the martensite) is essentially the same as the lath size. As a consequence, if the alloy is modified to suppress an unfortunate tendency toward intergranular fracture (which can be done, for example, by adding a microalloy addition of B [2]) the ductile-brittle condition in the as-quenched condition can be as low as 77 K (Fig. 2).

At the time the original research on Fe-12Mn was done [1,2] it was not at all clear why as-quenched Fe-12Mn developed this unique microstructure, though it was suspected that the hexagonal, ε martensite phase plays an important role. In Fe-12Mn the martensite start temperature, $M_{s\varepsilon}$, for the $\gamma \rightarrow \varepsilon$ transformation is slightly above that, $M_{s\alpha}$, for the $\gamma \rightarrow \alpha'$ transformation [3,4], so there is a partial transformation to the ε phase before the α' appears, and there is a significant residual content of ε phase in the as-quenched alloy (Fig. 1(b)). It was also not clear precisely why the effective grain size should be so small, since the crystallographic coordination of laths in conventional low-C dislocated martensite leads to effective grain sizes (block sizes) that are much larger than the lath size [5,8–10].

A partial answer to the latter question, the reason for the ultrafine grain size, was provided by recent research by Yi and Kim [11], who used high-resolution transmission electron microscopy (TEM) and electron back-scatter diffraction (EBSD) to make three important observations: (1) The prior austenite grains in 12Mn steel are subdivided into "packets" as in the more familiar lath martensitic steels, with the laths within the packet having the conventional Kurdjumov-Sachs (KS) relation with the parent austenite. (2) The columnar laths within a packet are organized into thin plates that

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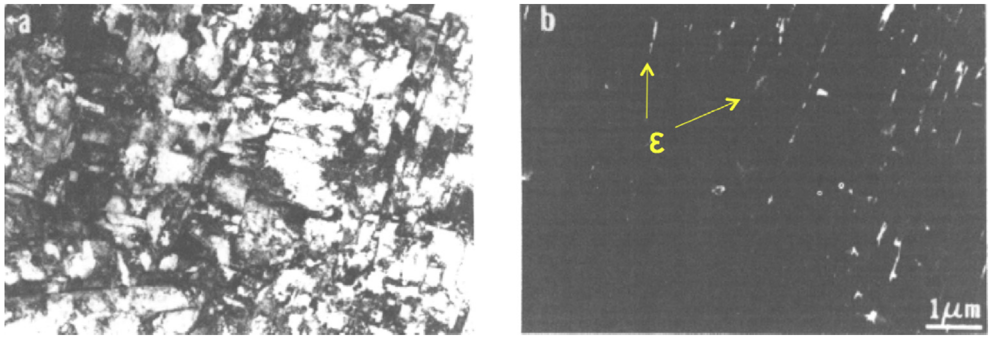

Fig. 1. (a) Bright-field TEM of as-quenched Fe-12Mn-0.1Ti-0.05Al showing fine-grained α' martensite. (b) Dark-field TEM showing distributed ε martensite in the α' matrix (from Ref. [1]).

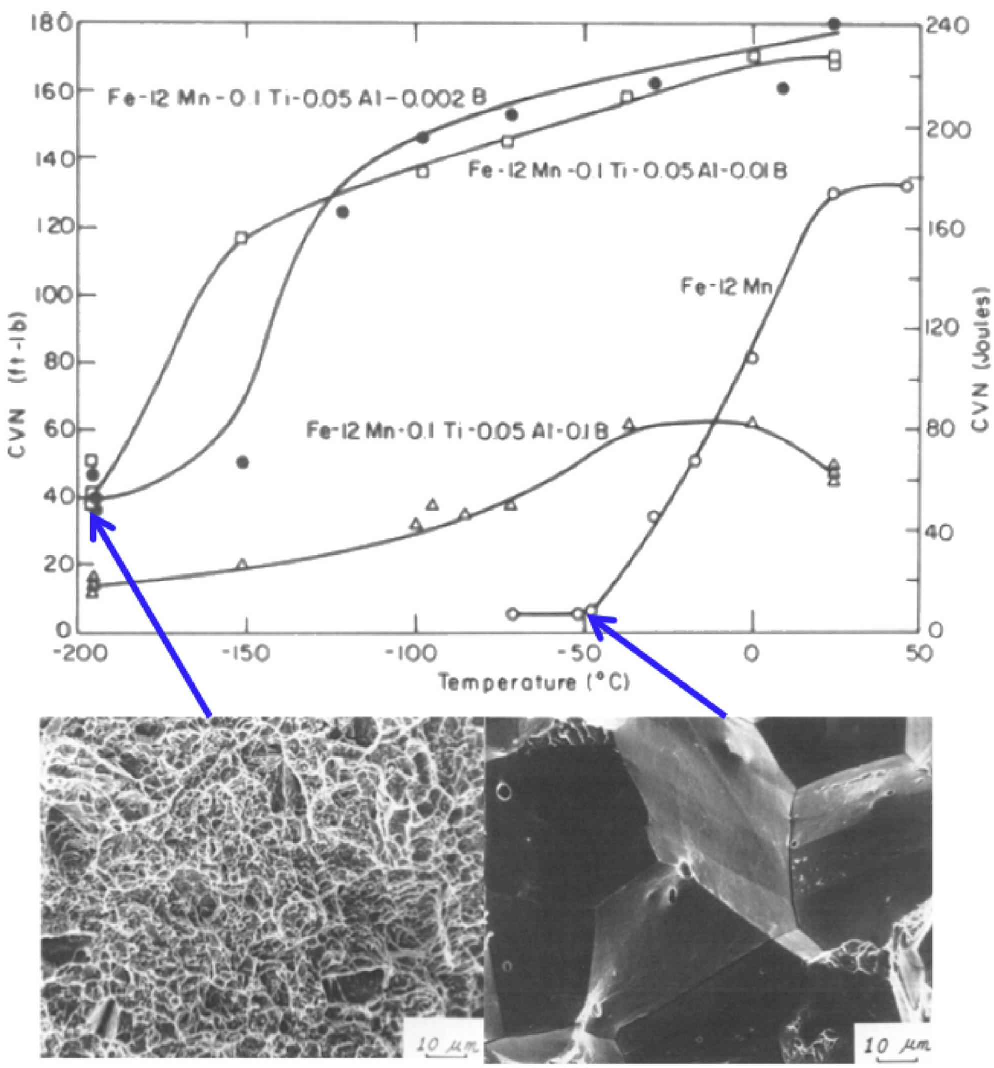

Fig. 2. Adding 0.002B to Fe-12Mn-0.1Ti-0.05Al changes the low-temperature fracture mode from brittle intergranular to ductile rupture and suppresses the ductile-brittle transition to cryogenic temperatures (from Ref. [3]).

stack on one another. (3) The adjacent laths within a plate have a strong tendency to be crystallographic twins of one another.

The latter observation explains the ultra-fine effective grain size of 12Mn steel. KS variants that are crystallographic twins have different "Bain axes" [8,9] and, hence, correspond to different "blocks" of the packet. The adjacent twinned laths act as independent grains in resisting cleavage fracture [8,12]. However, it remained unclear why Fe-12Mn should quench into this structure, which differs so much from that found in the usual low-C lath martensitic steel. The present research was undertaken to complete the characterization of the microstructure and identify the underlying reasons why it appears.