Packet Microstructure in Fe-0.2 pct C Martensite

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The arrangement, size, and boundary area of the laths that make up a packet of martensite in a coarse-grained Fe-0.2 pct C alloy were studied by replica and thin foil electron microscopy. Frequently laths of two habit plane variants coupled to a single (111)A plane of the parent austenite are observed in a packet. The width distribution of the laths is log normal, with the most frequently observed width being 0.15 microns. Larger laths between 1 and 2 microns are distributed throughout a packet. The total lath boundary area per unit volume of martensite obtained by analysis of micrographs taken from thin foils is quite high, 65,000 cm⁻², and analysis of packet structure by selected area diffraction and precision dark field techniques show that there may be five times as much low angle boundary area as high angle boundary area in a packet.

The martensite that forms in low carbon Fe-C alloys and steels divides the parent austenite grains into arrays of apparently parallel laths that are frequently referred to as packets. The first transmission electron microscope studies characterized this microstructure of low carbon martensite as needles arranged in sheets with 4 to 5 deg difference in orientation, but other evidence shows that within a packet there may be several different major orientations of the martensite laths. Light microscopy indicates that laths of one orientation are distributed within a matrix of other laths separated from each other by low angle boundaries, and evidence obtained from transmission electron microscopy shows that a packet may consist of bundles of slightly misoriented laths, each bundle being separated from its neighbors by high angle boundaries. Speich and his coworkers have shown that the Kurdjumow-Sachs orientation between austenite and martensite would account for various orientations, including some that are twin-related, between adjacent martensite units formed from a common austenite grain. Examples of sets of adjacent laths in three orientation categories predicted by the Kurdjumow-Sachs relationship were presented, but the results were not extended to the distributions of the various orientations throughout a packet of lath martensite. The size of the laths is also of interest in characterizing the microstructure of a packet. A number of investigators have reported average lath widths of about 0.2 microns in various low carbon steels, but a better representation of lath size within a packet appears to be a distribution ranging from many narrow laths 0.1 to 0.2 microns in width, well below the resolution of the light microscope, to occasional large laths, up to 2 microns in width, that are readily visible in the light microscope.

The purpose of the investigation described in this paper was to provide a more complete and quantitative description of the microstructure that makes up a packet of martensite. Two approaches were used. In the one, an extensive determination of lath width distribution within a packet was made from both replica and thin foil electron microscope specimens, while in the other, lath boundary area per unit volume was determined by quantitative analysis of transmission electron micrographs from packets of lath martensite. A value of 50,800 cm⁻² has been reported, but that result was based solely on replica measurements. An attempt was also made in the present work to estimate the amount of low and high angle lath boundary areas per unit volume in a packet. It is hoped that the results presented will be useful in comparing changes in martensitic microstructures that may be produced by alloying and/or by various heat treatments such as austenitizing and tempering.

MATERIAL AND PROCEDURE

The iron-carbon alloy used in this investigation was prepared by vacuum induction melting of electrolytic iron with graphite additions. After soaking at 1200°C for one hour the ingot was hot rolled to 1 inch in. plate. The chemical analysis in wt pct was: 0.20 C, < 0.01 Mn, < 0.003 P, 0.003 S, < 0.01 Si, 0.01 Ni, < 0.01 Cr, < 0.002 Mo, 0.002 Cu, < 0.002 V, < 0.005 Al, < 0.002 Sn, balance Fe. The plate was cut into 1 × 3 × 1 in. samples for replica work or cold rolled to 1/3 × 3 × 0.030 in. strips for thin foil material. All specimens were austenitized at 1100°C for 1 hr in evacuated vycor tubes and quenched to form martensite by breaking the tubes under water. The prior austenite grain size was 0.40 mm diam, corresponding to about ASTM grain size Number 0.

Thin foils for transmission electron microscopy were prepared by cutting 1/2 in. diam discs from strip specimens, grinding to 0.003 in. thickness on wetpaper, indenting on a spark discharge unit, and electrolytically polishing to perforation in a jet thinning apparatus with a solution of 796 ml acetic acid, 150 g CrO₃, and 40 g H₂O. Conventional two-stage replicas were prepared from the square cross-section samples which had been metallographically polished and etched. Thin foils were examined on a Philips EM 300 operated at 100 kV, while the replicas were examined on an RCA EMU 3G operated at 50 kV.

Lath widths were measured along straight test lines on enlarged electron micrographs showing areas of elongated, parallel laths. The test lines were oriented normal to the long direction of the parallel laths being measured. In the case of replica samples, 1205 laths were measured on eleven photographs at 20,000X. The lower limit of measurement on the replicas was 0.05μm.

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micron (1 mm at 20,000X), since the groove width at grain boundaries and the inherent resolution of the replica technique are of this order of magnitude. For thin foil specimens, 356 laths were measured on eight photographs at magnifications up to 76,000X. Analysis of the width distributions was based on intervals of 0.05 microns.

High and low angle lath boundaries in the thin foils were distinguished by precision dark field techniques. When a suitable area was located within a packet of laths, the bright field image and diffraction pattern were photographed. Often as many as six dark field photographs were then taken, corresponding to the more intense diffraction spots from the one or more distinct single crystal orientations in the diffraction pattern. After the diffraction pattern was indexed, the lath boundaries in the bright field photograph were traced on clear plastic and superimposed on each dark field photograph in turn. Laths illuminated by spots of different single crystal patterns were identified by different color codes on the tracing. Adjacent laths illuminated in dark field by diffraction spots from the same zone were assumed to be separated by low angle boundaries while those illuminated by beams belonging to zones of different orientation were assumed to be separated by high angle boundaries. An overlay consisting of a series of concentric circles was used to determine \( N_L \), the number of high angle, low angle, or undetermined boundary intersections per unit length of test line. \( S_V \), the boundary area per unit volume of martensite, was calculated for each of the categories from the relation \( S_V = 2N_L \).

RESULTS AND DISCUSSION

Figs. 1 and 2 are transmission electron micrographs of portions of the large packets of martensite that formed in the coarse austenite grains of the Fe-0.2 C alloy. The structures are complex, but representative patterns with respect to lath width and orientation emerge when the eye integrates over all the laths within the micrographs. With respect to size, there is a definite range of lath widths, up to 2 microns, with the different sizes more or less regularly distributed throughout a packet. There also appear to be two major directions of lath boundaries, also roughly uniformly distributed throughout a given packet. A discussion of this latter aspect, the arrangement of laths in a packet, precedes the discussion of lath width distribution in a packet. Finally the characterization of a packet by measurement of lath boundary area per unit volume of martensite will be discussed.

Arrangement of Laths

The directions of the lath boundaries represent the traces in the plane of the foil of the habit planes of the various laths that make up a packet, and the angles between the traces represent on the plane of the foil the dihedral angle between different variants of the lath habit planes. A determination of the habit plane of lath martensite in Fe-C alloys has yielded a habit close to \( \{557\}_A \). The angles between the traces of the predominant variants in each of the major packets in Figs. 1 and 2 range between 16 deg and 21 deg, corresponding very closely to the 16.3 deg angle between \( \{557\}_A \) habit planes clustered about a given \( \{111\}_A \).