Effects of Austenite Grain Size and Cooling Rate on Widmanstätten Ferrite Formation in Low-Alloy Steels

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Deformation dilatometry is used to simulate the hot rolling of 0.20 pct C-1.10 pct Mn steels over a product thickness range of 6 to 170 mm. In addition to a base steel, steels with additions of 0.02 pct Ti, 0.06 pct V, or 0.02 pct Nb are included in the study. The transformation behavior of each steel is explored for three different austenite grain sizes, nominally 30, 55, and 100 μm. In general, the volume fraction of Widmanstätten ferrite increases in all four steels with increasing austenite grain size and cooling rate, with austenite grain size having the more significant effect. The Nb steel has the lowest transformation temperature range and the greatest propensity for Widmanstätten ferrite formation, while the amount of Widmanstätten ferrite is minimized in the Ti steel (as a result of intragranular nucleation of polygonal ferrite on coarse TiN particles). The data emphasize the importance of a refined austenite grain size in minimizing the formation of a coarse Widmanstätten structure. With a sufficiently fine prior austenite grain size (e.g., ≤30 μm), significant amounts of Widmanstätten structure can be avoided, even in a Nb-alloyed steel.

I. INTRODUCTION

When proeutectoid ferrite exhibits a morphology consisting of needlelike or plate-shaped grains, this structure is often referred to as Widmanstätten ferrite, after the French scientist Alois de Widmanstätten. Although Widmanstätten ferrite usually nucleates at ferrite grain boundary allotriomorphs, it can also form at intragranular sites, such as nonmetallic inclusions. According to the Dubé morphological classification system, the grain-boundary-allotriomorph–nucleated structures are termed Widmanstätten sideplates. An example of Widmanstätten sideplates growing from a grain boundary allotriomorph is provided in Figure 1(a). In contrast, the intragranularly nucleated Widmanstätten ferrite has been referred to as acicular ferrite. In this article, we will use the term Widmanstätten ferrite to broadly describe both types of needlelike ferrite.

In steel microstructures, Widmanstätten ferrite usually occurs as an aggregate with carbides/pearlite and is difficult to quantify as a separate microconstituent. To simplify microstructural analysis, the needlelike Widmanstätten ferrite/pearlite aggregates are treated as an individual constituent and referred to as "Widmanstätten structure" in this article. In contrast, polygonal ferrite can occur as grain boundary allotriomorphs and intragranular idiomorphs, both commonly found in steel microstructures. For example, Figure 1(b) shows a microstructure in which polygonal ferrite (i.e., grain boundary allotriomorphs) has nucleated at prior austenite grain boundaries. The interior of the prior austenite grains consists of a needlelike ferrite/pearlite aggregate, i.e., the Widmanstätten structure.

In addition to its occurrence in as-rolled steels, Widmanstätten ferrite has been observed in accelerated cooled steels, normalized steels, the heat-affected zones of welds, and weld metals.
II. EXPERIMENTAL PROCEDURES

A. Preparation of Steels

The four structural steels investigated were laboratory air-induction melted and cast into 225-mm square, 225-kg ingots. These ingots were then reheated to 1260 °C and hot-rolled to 13-mm-thick plates. The compositions of the four steels, with nominal C and Mn levels of 0.20 and 1.10 pct, respectively, are listed in Table I. In addition to the base C-Mn steel, there are microalloy addition (Ti, V, Nb) on Widmanstätten ferrite formation in a 0.20 pct C-1.10 pct Mn steel. Another article addresses the effects of Widmanstätten ferrite on the mechanical properties of a C-Mn steel.

B. Austenite Grain Coarsening

To understand the austenite grain coarsening behavior in these steels, small specimens (13-mm thick by 25-mm square) were austenitized for one-half hour at temperatures between 925 °C and 1370 °C and water quenched. The specimens were then metallurgically prepared, and after suitable etching, the average prior austenite grain size was determined using the circular intercept method of ASTM E112.

C. Deformation Dilatometry

Cylindrical dilatometer pins measuring 4 mm in diameter by 8 mm long were machined from the as-rolled plates. The pins were heated to either 1200 °C or 1260 °C in an inert atmosphere. The austenite grain size was determined using a Materials Measuring Corporation deformation dilatometer and a heating rate of 200 °C/min. After holding at the reheating temperature for three minutes, the steels were thermomechanically processed as shown in Table II to produce nominal prior austenite grain sizes of either 30, 55, or 100 μm. Having established the desired austenite grain size, the steels were control cooled to ambient at cooling rates between 10 °C/min and 12,000 °C/min (average cooling rates between 800 °C and 500 °C).

To correlate cooling rate with product thickness, 150-mm-square alloy steel plates with thicknesses of 13, 25, 38, 50, 75, and 100 mm were instrumented with thermocouples at surface, quarter thickness, and midthickness locations (in the middle of the plate). The plates were then heated to, and equalized at, 900 °C and air-cooled. Average cooling rates were determined between 800 °C and 500 °C. For comparison, equivalent midthickness plate cooling rates (at 700 °C) for normalizing were converted from bar center data using the Jominy correlation developed by Boegehold and Weinman, viz.

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equivalent \text{ plate thickness} = 0.75 \times \text{equivalent bar thickness}
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D. Metallography

The dilatometer pins were mounted longitudinally in epoxy, polished to a midradius plane, and etched sequentially in 4 pct picral and 2 pct nital solutions. Quantitative metallography was confined to the central region of the pins, where the microstructure was uniformly refined (i.e., the dead zones associated with friction at the specimen ends were avoided). Austenite grain sizes were determined, using the circular intercept method of...