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The formation mechanisms of interlocked microstructures in low-carbon high-strength steel weld metals

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ABSTRACT

Microstructural features and the formation mechanisms of interlocked microstructures of acicular ferrite in a low-carbon high-strength steel weld metal were investigated by means of computer-aided three-dimensional reconstruction technique and electron backscattered diffraction analysis. Multiple nucleation on inclusions, sympathetic nucleation or repeated nucleation, hard impingement, mutual intersection, and fixed orientation relationships of acicular ferrite grains were observed. They were all responsible for the formation of interlocked microstructures in the weld metal. During the process of isothermal transformation, the pre-formed acicular ferrite laths or plates partitioned austenite grains into many small and separate regions, and the growth of later formed acicular ferrite grains was confined in these small regions. Thus, the crystallographic grain size became smaller with the increasing holding time.

1. Introduction

It is generally accepted that the mechanical properties of weld metal and the heat-affected zone are mainly dependent on their microstructures [1]. Acicular ferrite microstructure in weld metals and the heat-affected zone provided optimum mechanical properties, both in terms of strength and toughness, by virtue of the fine-grained and interlocked microstructures [2]. Many experiments have been done on the characteristics and formation conditions of acicular ferrite in steels. The nature [2,3], morphology [4], orientation relationship [5–9], and mechanical property [10] of acicular ferrite were extensively studied. The nucleation mechanisms of acicular ferrite are well understood and summarized as the solute depletion in the vicinity of non-metallic inclusions [11–13], the reduced interfacial energy between acicular ferrite and inclusions [6], the thermal strain energy caused by the different expansion coefficients of the inclusion and the matrix [6], and the provision of an inert surface [14]. Chemical composition of steel [15], isothermal temperature [16], continuous cooling rate [17], and austenite grain size [18] also have much influence for the formation of acicular ferrite.

Based on two-dimensional (2-D) observations, Rick et al. [3] indicated that the interlocked microstructures of acicular ferrite were formed by some primary ferrite plates nucleated by inclusions and many secondary plates sympathetically nucleated on the austenite boundaries and/or primary ferrite plate surfaces. Terasaki et al. [19] recently reported that the impingement events of acicular ferrite were also attributed to the formation of interlocked microstructures by in situ observations. However, observations by means of optical microscopy were ordinarily made on 2-D polished planes, many features of microstructure could easily be missed owing to the fact that a large part of microstructure was embedded beneath the polished surface, or removed during specimen preparation [20]. In recent years, the advantages of three-dimensional (3-D) microstructural analysis have been reviewed by Kral and Spanos [20]. Serial sectioning and computer-aided three-dimensional visualization have emerged as a useful technique, and often play an essential

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Table 1 – Chemical composition of the weld metal (mass %).

C	Si	Mn	Ti	Al	S	N	O
0.041	0.56	1.53	0.067	0.019	0.016	0.0056	0.086

role in identification of transformation mechanism and quantitative analysis of microstructure [21]. Meanwhile, a new nonaqueous solution electrolysis method was used to investigate the 3-D morphology and interior characteristic of inclusion, which would be undamaged to separate from the steel matrix [22]. Because it is difficult to determine the effective grain size of the fine-grained mixed intermediate transformation microstructures, such as acicular ferrite, bainite, and martensite using traditional metallography. Electron back scattered diffraction (EBSD) enables the determination of phase and crystallographic orientation. The size and relative location of grain boundaries, phases, and grains in the sample can be conveniently determined using crystallographic information [23].

Fig. 1 – Optical micrograph of a specimen taken from weld metal before heat treatment.

In the present work, serial sectioning and computer-aided three-dimensional reconstruction technique in conjunction with EBSD analysis were utilized to further investigate the formation mechanisms of fine-grained and interlocked microstructures of acicular ferrite in weld metals.

2. Experimental Procedures

The specimens were prepared by flux-cored arc welding. The chemical composition of the weld metal is shown in Table 1. The specimens taken from weld metal were austenitized at 1200 °C for 20 min and furnace-cooled to increase the austenite grain size. They were subsequently austenitized at 1350 °C for 150 s under a purified argon atmosphere, and then immediately transferred to a salt bath, isothermally reacted at 570 °C and 600 °C for varying times, followed by water quenching.

Samples (80 mm × Φ10 mm) taken from weld metals were electrolyzed in a nonaqueous solution, its pH value being 8.

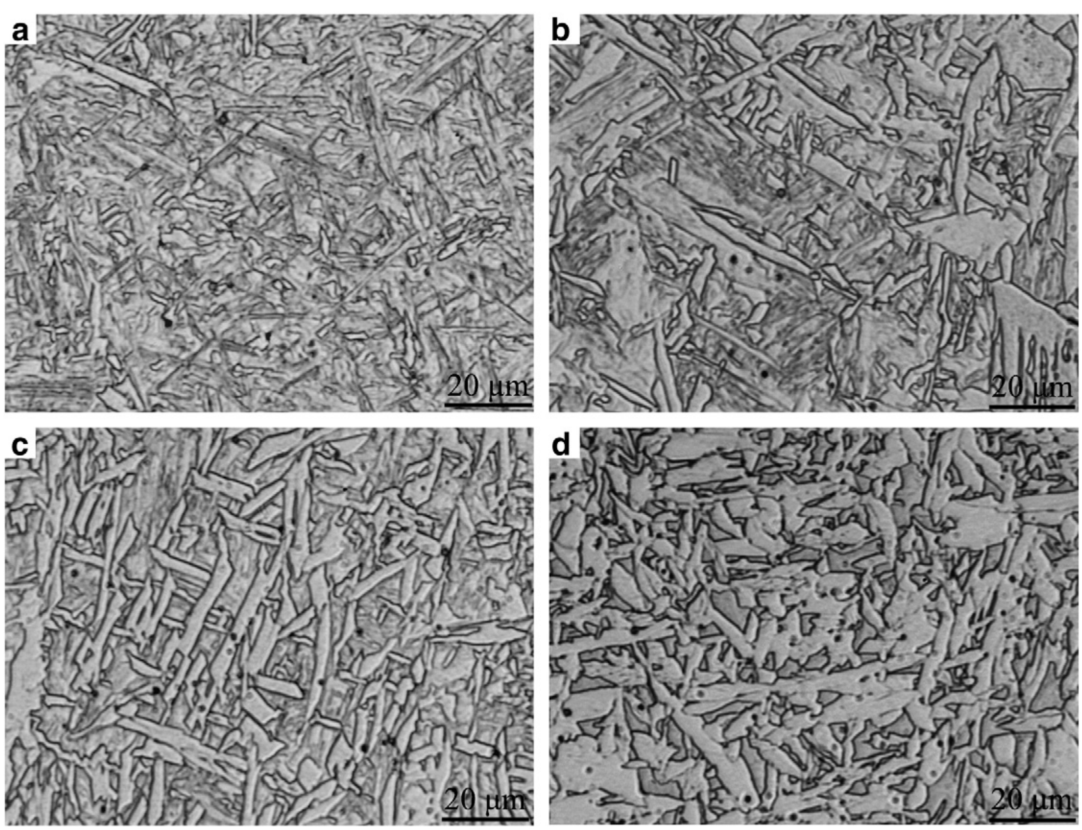

Fig. 2 – Optical micrographs of the specimens austenitized at 1350 °C for 150 s and isothermally held at 570 °C for (a) 1 s, (b) 5 s, (c) 10 s and (d) 15 s, respectively.