

Thermodynamic Analysis of Inclusion Formation for Weld Microstructure Control

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In this work, microstructure control by the dispersion of fine particles has been analyzed from a thermodynamic viewpoint. Based on the experiment of the formation of acicular ferrite in low-carbon steel weld metal, the presence of catalysts and rapid cooling were the important factors for microstructure control. Ti-particles can act as effective inoculants for the formation of fine-grain microstructure during solidification.

INTRODUCTION

As the use of high tensile-strength steels and the high heat input welding process increases in many structural applications, the refinement and control of weld microstructure become more critical to assure the toughness of the welds.

The microstructure of weld metal and the heat affected zone (HAZ) is refined by different inclusions, of which some act as a nucleation site of acicular ferrite, and some as pinning particles against the grain growth of austenite.

In this paper, inclusion-assisted microstructure control technologies are reviewed to improve the microstructures in the weld metal of steels.

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The main subject of this paper is the thermodynamic analysis of particle-dispersion in metallic structures on the basis of phase diagram and nucleation phenomena.

In the 1980s, some researchers—Komizo (1982), Abson (1979), Mori (1981), Ito (1981), and Farrar (1987)—proposed a new concept for producing fine-grained microstructure, the so-called acicular ferrite using Ti as a deoxidizer. By virtue of its small grain size and high angle boundaries, acicular ferrite is regarded as the most desirable microstructural feature, from the strength and toughness point of view, in low-alloy steel weld metals. Fig. 1 (Komizo, 1982) shows the acicular ferrite observed in a 0.11% C-0.29% Si-1.16% Mn-0.043% Ti-0.0034% B-0.020% oxygen weld metal. The acicular ferrite nucleates primarily on inclusions remaining within prior-austenite, and it grows with fine acicular morphology, which typically has an aspect ratio of 2 to 10 with a width of submicron to a few micron m (Komizo, 1982; Bhadeshia, 1993). More recently, many studies (Rees, 1994; Babu, 1999, 2002) from various angles have attempted to establish the mechanism underlying inclusion utilization technology.

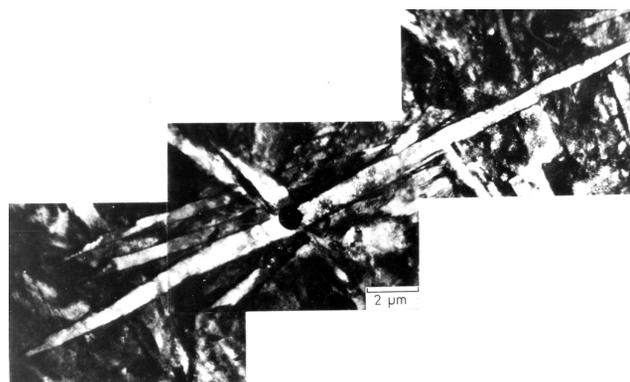


Fig. 1 Acicular ferrite observed in low-carbon steel weld metal cooling down to 500°C and water-quenched

As a result of such work, it has become obvious that the principal process mechanism in inclusion utilization technology is mainly operative in the nucleation stage. However, as there are always difficulties in identifying the key factors in such nucleation problems, a trial attempt at providing a thermodynamic basis of inclusion utilization technology has been made as follows.

CLASSIFICATION OF DISPERSED PARTICLES

The way the dispersed particles function in a metal matrix depends mainly on their chemical compatibility with the Fe matrix. In this work, this compatibility has been roughly estimated from the phase equilibria in the liquid Fe-M-X systems; Fig. 2 illustrates the typical ones among them.

Most of the carbides and nitrides are covalent crystals that are generally soluble in liquid metals in all proportions. On the other hand, the oxides and sulfides are mostly ionic, and hardly soluble in liquid metals, tending to form slag or matte above liquid metal. However, there are a few exceptions to this rule, as typified by AlN and TiO in particular.

TiO is not ionic but metallic, and the Ti-TiO system has a wide range of solubility even in the solid state, as shown in Fig. 2. It can then be said that the Fe-TiO equilibrium in the liquid state is similar to the metallic system with a liquid phase miscibility gap. On the other hand, while AlN is a nitride, it is an ionic crystal and the Al-AlN system is a monotectic type, showing exten-

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