STEEL MICROSTRUCTURAL MAPPING SERIES

by: Reza Fadhila

MICROSTRUCTURAL MAPPING OF HADFIELD MANGANESE STEEL-3401 IN AGING TREATMENT

ABSTRACT

Hadfield steel used for railroad tracks was investigated for microstructural changes due to an aging treatment regime. The steel was subjected to solution treatment by heating at a temperature of 1000°C-1090°C and then water quenched. The as-quenched material was then investigated for the development of microstructure in an aging treatment by heating at various temperatures (400°C, 450°C, 500°C, 550°C and 600°C) and at two holding times (30min, 60min).

The ensuing microstructure was then examined for morphology using scanning electron microscopy (SEM) and verified for elemental analysis using X-ray diffractratometry (XRD) as well as X-ray fluorescence spectroscopy (XRF).

Results of the morphological mapping showed that at lower temperatures, ferrites grow in the form of sheaves of parallel plates which nucleated at austenite grain surfaces. At a higher temperature, the ferrites gave way to acicular ferrite plates, growing in many different directions. A new phase was formed in the 400°C to the 550°C which was confirmed as to be the transformation amorph bainite to the accicular bainite. The upper threshold for pearlite formation was at 600°C when again the ferritic structure was observed. The XRD and XRF data showed that the phase transformation observed in the morphological mapping matched.

Keywords: Austenitic manganese steel 3401, Air cooling, Microstructural Mapping
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Introduction

During the late of 1920s, in the course of pioneering studies on the isothermal transformation of austenite at temperatures above that at which martensite first forms, but below that at which fine pearlite is found, Davenport and Bain (1939) discovered a new microstructure consisting of an ‘acicular, dark etching aggregate’ which was ‘Bainite’ in honour of their colleague E. C. Bain.

The high-range and low-range variants of bainite were later called ‘upper bainite’ and ‘lower bainite’ respectively (Mehl, 1939) and this terminology remains useful. High-carbon steels can sometimes transform to plates of lower bainite which do not have a homogeneous microstructure (Okamoto and Oka, 1986). Bainite grows in the form of clusters of thin lenticular plates or laths, known as sheaves. Both upper and lower bainite were found to consist of aggregates of parallel plates, aggregates which were later designated sheaves of bainite (Aaronson and Wells, 1956). Isothermal transformation experiments led to the clarification of microstructures, describes as massive ferrite, grain boundary ferrite, acicular ferrite, Widmannstätten ferrite, etc. Ferrite which grows by a diffusional mechanism can be classified into two main forms: allotriomorphic ferrite and idiomorphic ferrite (Dubé 1948; Aaronson, 1955; Dube et al., 1958).

The term 'allotriomorphic' means that the phase is crystalline in internal structure but not in outward form. It implies that the limiting surfaces of the crystal are not regular and do not display the symmetry of its internal structure (Christian, 1975). Thus, allotriomorphic ferrite which nucleates at prior austenite grain boundaries tends to grow along the g austenite boundaries at a rate faster than in the direction normal to the boundary plane, so that its shape is strongly influenced by the presence of the boundary and hence does not necessarily reflect its internal symmetry. Of course, allotriomorphic ferrite need not form just at g austenite boundaries, but it invariably does so, presumably because there are no other suitable (two-dimensional) heterogeneous nucleation sites in austenite. In the other hand the term ‘idiomorphic’ implies that the phase concerned has faces belonging to its crystalline form; in steels, idiomorphic ferrite is taken to be that which has a roughly equiaxed morphology. Idiomorphic ferrite usually forms intragranularly (Dubé, 1948), presumably at inclusions or other heterogeneous nucleation sites. In reality, the cementite and ferrite within a given colony are single crystals, the lamellae of each phase being connected in three dimensions (Hillert, 1962). With the exception of the ferrite found within pearlite, all other ferrite morphologies involve plate or lath shapes...
The sample of the Hadfield’s manganese steel used was Krupp 3401 with the chemical composition as shown below:

<table>
<thead>
<tr>
<th>Composition</th>
<th>standard a</th>
<th>Modified b</th>
<th>Modifiedc</th>
</tr>
</thead>
<tbody>
<tr>
<td>% C</td>
<td>1.0-1.2</td>
<td>1.059</td>
<td>-</td>
</tr>
<tr>
<td>% Mn</td>
<td>11-14</td>
<td>11.34</td>
<td>11.36</td>
</tr>
<tr>
<td>% Si</td>
<td>-</td>
<td>0.3694</td>
<td>0.6252</td>
</tr>
<tr>
<td>% Ni</td>
<td>-</td>
<td>0.1345 (Zr)</td>
<td>0.0599</td>
</tr>
<tr>
<td>% Cr</td>
<td>-</td>
<td>0.1362</td>
<td>0.1668</td>
</tr>
</tbody>
</table>

*a. Standard Hadfield’s steel as theoretical  
b. Actual analysis composition by Spectrometer (PT KIM)  
c. Actual analysis composition by XRF*

The chemical composition was found using spectrometry and validated by XRF. Test specimens of 10 x 20 x 25 mm were prepared for metallographic inspection. Samples were heat-treated at 1050°C for 1 hour in a PID electric furnace (Vector VHT-3), then quenched in water. Samples were reheat-treated at different temperatures for various holding times. Temperatures were set between 400°C to 600°C at 50°C intervals. After heating at 30 and 60 minutes, the sample were air cooled. The samples were ground and polished using silicon carbide abrasive paper and alumina paste 1µm to obtain a mirror like surface, and then the sample was cleaned by using the ultrasonic cleaning machine, Branson 1210, Model B1210E-MT 47 KHz, 230 Volt and etched using the etchant as shown.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution A</td>
<td>100 ml alcohol</td>
</tr>
<tr>
<td>Solution B</td>
<td>90 ml ethanol</td>
</tr>
<tr>
<td>Solution C</td>
<td>100 ml ethanol</td>
</tr>
</tbody>
</table>

The microstructure was obtained an optical image analyser microscope at 100X magnification.
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Research Flowchart Diagram

- Hadfield Fe Mn Steel 3401
- Solution Treatment Process
- Aging Treatment 400°C, 450°C, 500°C, 550°C, 600°C
- Aging Time: 30, 60 Minutes
- Metallography Inspection
- Microstructure Mapping

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1. This paper presents the microstructural development of the austenitic manganese steel-3401 due to aging treatment in different heating regimes followed by air cooling process. The material is heated to 1050ºC followed by a rapid cooling process which caused the solid solution of the carbides to be precipitated in the grain of the pure austenite phase. By reheating this austenite phase in two region phase area, a partial dispersion of austenite will occur. The time and temperature of tempering will affect the dispersion area in the austenite phase.

2. Development in microstructure mapping resulting from such studies should also enriching phenomena in the subject of applied physical metallurgy. The study helps to understand better about the previous kinetic aspects in phases and microstructure development for manganese steel alloys. Properties such as excellent toughness and good wear resistance are expected in produce in future.

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Microstructural Mapping of Hadfield Manganese Steel-3401 in Aging Treatment

MANGANESE STEEL MICROSTRUCTURE

AGING BY AIR COOLING PROCESS:

Display a set of image analyzer microstructure air-cooling contains and how the phenomena are related.

Material & Methods

Research Flowchart

Objective

Result & Discussion
Development of microstructure at heating regimes of 1050°C following by water quenching.

The microstructure of Hadfield’s austenitic manganese steel when heat treated to 1050°C then followed by rapid cooling process is shown in Fig. 1.

Fig. 1 shows austenite grains of 3401 Hadfield’s steel twins after quenching.
Figure 1B showing the microstructure of Hadfield’s austenitic manganese steel after heating to 1050°C then subsequently reheated at 400°C at 30 minutes followed by air cooling condition.

The initially forming of bainite structure which still get involved in the austenite structure. The primarily appearance of bainite structure in austenite structure.
Fig. 1 C Treatment 1050°C—Water Quench
Aging 400°C—60 Minutes

Showing the microstructure of Hadfield’s austenitic manganese steel after heating to 1050°C then subsequently reheated at 400°C for 60 minutes followed by air cooling condition. Initially forming of bainite structure still get involved in the austenite structure. The primarily appearance of bainite structure in austenite structure wherein condition seem excessively than in 400°C for 30 minutes.
Fig. 1D  Treatment 1050°C—Water Quench  
Aging 450°C—30 Minutes

showing the microstructure of Hadfield’s austenitic manganese steel after the treatment of 1050°C subsequent reheating to 450°C for 30 minutes followed by air cooling process. Ferrite which formed first was variously describes as massive ferrite. Massive ferrite, which also grows by a diffusional transformation mechanism, has the distinction that it inherits the composition of the parent austenite.

The extent of penetration into particular grains may vary since interface mobility can change with the α/γ orientation relationship.
Microstructure of Hadfield’s austenitic manganese steel after the treatment of 1050°C subsequent reheating to 450°C for 60 minutes followed by air cooling process.

Ferrite which formed first was variously described as grain boundary ferrite. Massive ferrite, which also grows by a diffusional transformation mechanism, has the distinction that it inherits the composition of the parent austenite. The extent of penetration into particular grains may vary since interface mobility can change with the \( \alpha/\gamma \) orientation relationship. Allotriomorphic ferrite which nucleates at prior austenite grain boundaries tends to grow along the \( \gamma \) austenite boundaries at a rate faster than in the direction normal to the boundary plane, so that its shape is strongly influenced by the presence of the boundary and does not necessarily reflect its internal symmetry. Allotriomorphic ferrite need not form just at \( \gamma \) austenite boundaries, but it invariably does so, presumably because there are no other suitable heterogeneous nucleation sites in austenite.
Results & Discussion

The austenite grain boundaries are well defined and of approximately uniform thickness has also reported that the Hadfield’s manganese steel with a composition of Fe-1.2%C and 13%Mn, normally has a structure of metastable austenite phase which is obtained by water-quenching the steel from annealing temperature of 1050°C. It results in the solid solution of carbides causing brittleness and the production of almost pure austenite.

When aged, partial decomposition of the austenite occurs. The extent of this decomposition depends on the time and temperature of the tempering treatment. Microstructural examination of the samples showed the formation of bainite begins by precipitation of iron and manganese carbides at the grain boundaries, then progressively followed by the appearance of a new constituent which later extended into its grain.

The lower bainite is actually found to evolve in two stages from thin-plate martensite which forms by the isothermal transformation of austenite, and stimulates the growth of the adjacent bainite regions. As the temperature and holding time is increased, several microstructures developed; an appearance of bainite in austenite structure, then massive ferrite and grain boundary ferrite. The nomenclatures becomes confused since the ferrite which formed first was variously describes as massive ferrite, grain boundary ferrite, acicular ferrite, Widmannstätten ferrite, etc.

Since both idiomorphic and allotriomorphic ferrite grow by a diffusional transformation mechanism, their growth is not restricted by austenite grain boundaries. The extent of penetration into particular grains may vary since interface mobility can change with the a/g orientation relationship. Massive ferrite, which also grows by a diffusional transformation mechanism, has the distinction that it inherits the composition of the parent austenite. The ability to cross parent austenite grain boundaries is particularly pronounced during massive transformation; the final ferrite grain size can be larger than the initial grain size of the g. Allotriomorphic, idiomorphic and massive ferrite can only be fully appreciated in the context of the other microstructural constituents which also arise in steels. The formation of pearlite in steels involves the co-operative, diffusional growth of ferrite and cementite from austenite. In two-dimensional sections, this eutectoid mixture appears to consist of alternate lamellae of ferrite and cementite, which together form a pearlite colony.

The ensuing microstructures obtained and objective of the research are shown in the image analyzer gallery page.