Low-temperature Bainite

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Motivation

Characterisation, tempering of novel bainitic microstructure

- Atomic force microscopy of shape deformation
- Mechanical property changes during tempering
- Microstructural changes during tempering
- Compositional changes during tempering
- Theory (lattice parameters, hardness)
- Techniques: X-ray, atom-probe, microscopy, mechanical properties, modelling theory
What is the novelty in the microstructure of so-called 'super-bainite'?

Forms at very low temperatures.

Tiny plates.

Very tempering resistant.

Wonderful mechanical properties in dirty state.
## Composition

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Mo</th>
<th>Cr</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt %</td>
<td>0.75</td>
<td>1.63</td>
<td>1.95</td>
<td>0.28</td>
<td>1.48</td>
<td>0.1</td>
</tr>
<tr>
<td>At %</td>
<td>3.34</td>
<td>3.1</td>
<td>1.9</td>
<td>0.16</td>
<td>1.52</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Low Temperature Bainite

Isothermal transformation at 200°C for 10 days
Fe-2Si-3Mn wt%

![Graph showing the relationship between time and carbon content for Fe-2Si-3Mn alloy. The x-axis represents carbon content in wt%, ranging from 0 to 1.5, and the y-axis represents time in seconds, ranging from 1x10^4 to 1x10^8. The graph includes markers for 1 month and 1 year.](image_url)
Maraging steels

QT martensite
Bainite: diffusionless growth. Excess carbon subsequently partitioned into austenite.
Mystery of Carbon Content

Calculated from Lattice parameter of ferrite

Can we believe these results?
Tempering Resistance

\[ Q \sim 182 \text{ kJ mol}^{-1} \]

Activation energy for carbon diffusion is 50 kJmol\(^{-1}\)

\[ \sim 200 \text{ kJmol}^{-1} \] for bulk diffusion of substitutional elements.
Aus1 fully transformed after 200°C for 10 days
Aus1 fully transformed after 200°C for 10 days
+ 30 min at 400°C
+ 1 h at 550°C
+ 1 h at 450°C
+ 24 h at 600°C
Each dot is an atom, its position and composition known.

Atom Probe

Ferrite

Austenite
Carbon distribution in low temperature bainitic steel
Collosal (12 at%) in austenite
Impressive (1.8 at%) in ferrite
Substitutional / Solvent atom ratio constant between ferrite and austenite.
Carbon concentration; 10 at% in Austenite
1.5 at% in ferrite
Uniform substitutional solute distribution
As expected for displacive transformation
Nothing new about finding excess carbon in ferrite!

Waugh and Bhadeshia (81,82) – atom probe
Self et al. (80) – lattice imaging
Stark et al. (90) – atom-probe

Persistance of carbon in ferrite is original contribution, verified by X-ray and atom probe.
Carbon Atom Map after temper for 30 mins at 400°C
Concentration profiles, low temperature bainite tempered for 30 mins at 400°C

Ferrite ~2 at% C
Carbon atom map after tempering 30 mins at 500°C
Concentration profiles for low temperature bainite tempered for 30 mins at 500°C

Ferrite ~1 at% C
Conclusions

Ferrite transforms without diffusion.

a large supersaturation of carbon in ferrite.

Partitions to austenite thin films, to extent slightly greater than $T_0$ value.

X-ray concentrations consistent with atom probe.

Excess carbon trapped at defects, therefore hessitant to precipitate.
Minute iron carbides cause hardening.

Secondary hardening due to cementite! (carbon concentrated into austenite, and then dumped at the ferrite boundaries)

Carbides prevent plates from recrystallising.
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