The bainite controversy

Annika Borgenstam
Department of Materials Science and Engineering
KTH, (Royal Institute of Technology)
Stockholm
SWEDEN

Acknowledgements:
Mats Hillert, Peter Hedström, Peter Kolmskog,
Albin Stormvinter and John Ågren

The two conflicting hypothesis of the mechanism of bainite formation

Both based on
Ko and Cotrell, 1952

- Observed a surface relief - support for the rapid mechanism without diffusion of carbon
- Observed slow growth rate – support for the diffusional mechanism

Can we resolve the controversy?

Diffusional hypothesis

Bainitic and Widmanstätten ferrite

- grow by the same mechanism
- controlled by carbon diffusion
- paraequilibrium
- thermodynamic barrier

Diffusionless hypothesis

Widmanstätten ferrite

- slower
- no subunits
- diffusion of C
- barrier of 50 J/mol
- not below Bs

Bainite

- rapid steps
- small subunits
- no C diffusion
- barrier of 400 J/mol
- not above T0 or T0'
- cementite precipitates from supersaturated ferrite in lower bainite

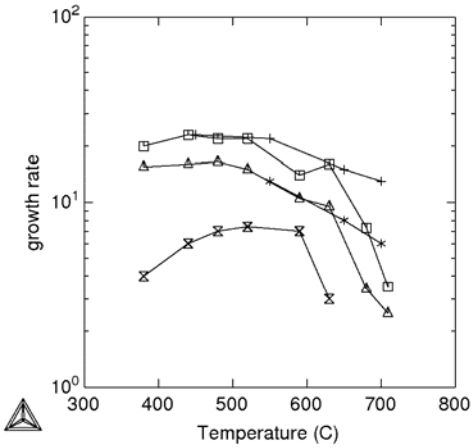
The following discussion:

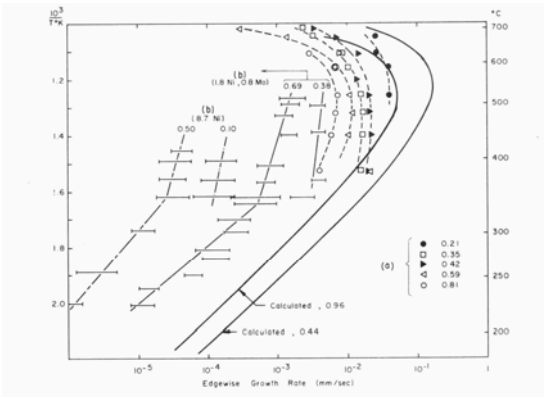
- will ***not*** concern if bainite is formed by a displacive mechanism or not.
- will only concern if bainite is formed by diffusion of C or not.

How to test the diffusional hypothesis?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?

Is there a break in the kinetic behaviour at Bs?

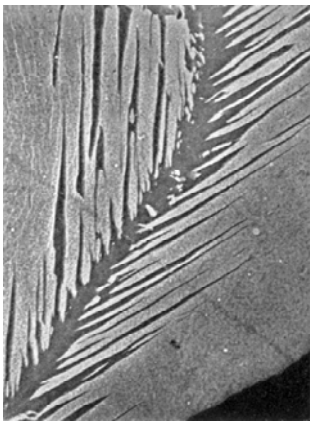


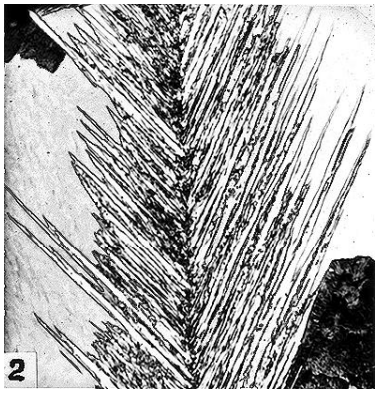


Exp data: Hillert 1960, Simonen et al 1973

Kaufman et al 1960

Is there a sudden change of the morphology of acicular ferrite at some temperature?

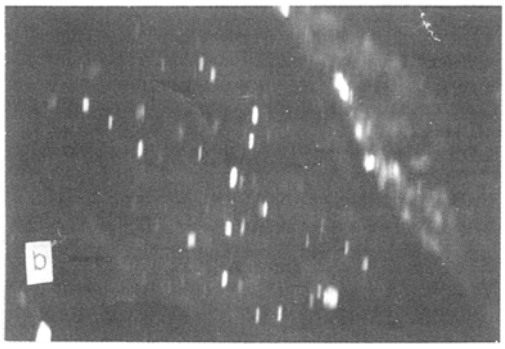




How to test the diffusional hypothesis ?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?
2. Has it been shown that carbides precipitate inside bainitic ferrite?

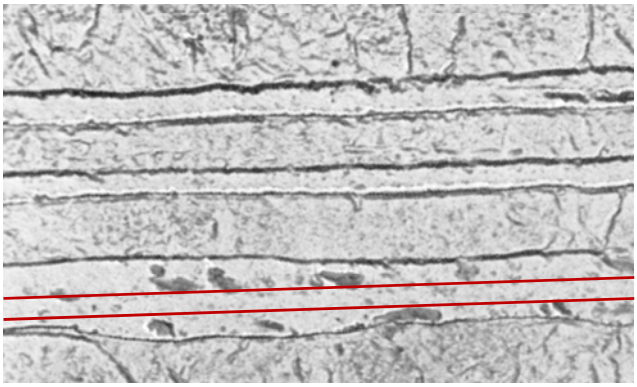
When did the carbides precipitate within bainitic ferrite?



After tempering for 20 min at 753 K. Kang et al, 1990.

Not possible to say, but there has been plenty of time for carbon to diffuse.

Why are there no carbides in the primary ferrite plate?

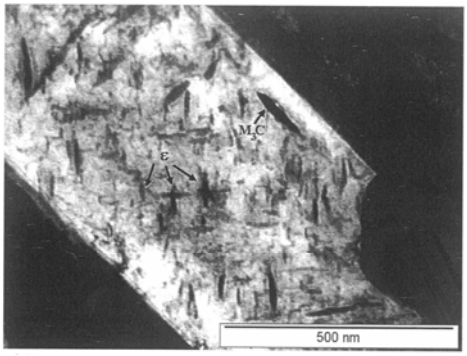


F.B. Pickering, 1960

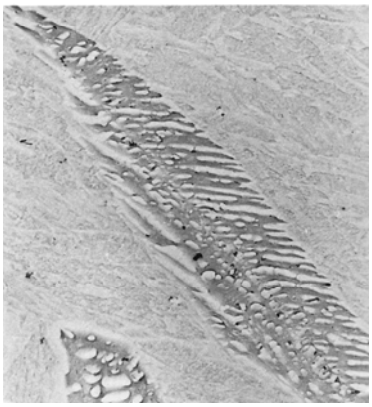
How to test the diffusional hypothesis?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?
2. Has it been shown that carbides precipitate inside the bainitic ferrite?
3. Do carbides in tempered martensite and in lower bainite look the same?

Do carbides in tempered martensite and in lower bainite look the same?



Tempered martensite
Andersson et al 2008



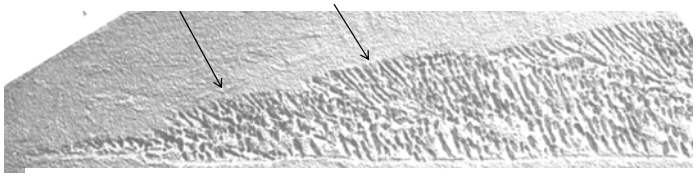
Lower bainite, 12000x
Schrader and Wever, 1952

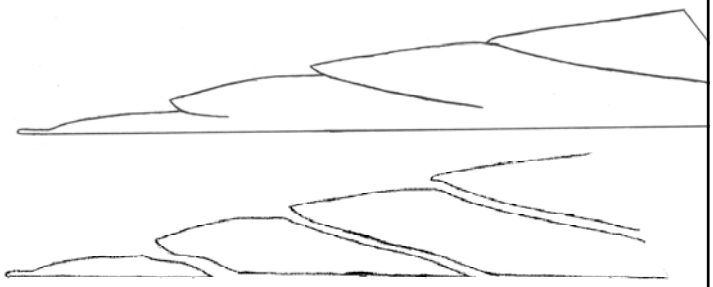
How to test the diffusional hypothesis?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?
2. Has it been shown that carbides precipitate inside the bainitic ferrite?
3. Do carbides in tempered martensite and in lower bainite look the same?
4. Do subunits form by gradual growth or by successive rapid steps?

Can the subunits be explained by gradual growth or by successive rapid steps where each one fully forms before the next one?

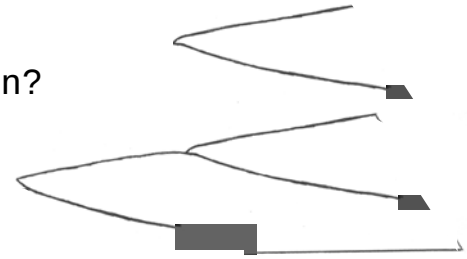
Oblak and Hehemann, 1967: indicated the subunits with arrows:



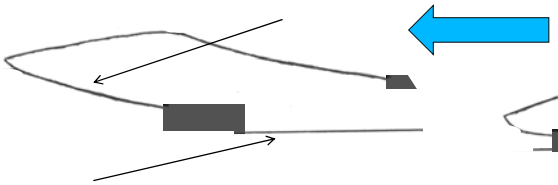


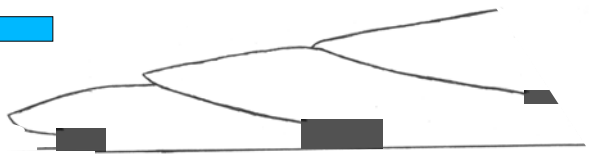
Let us separate the subunits:

Can the subunits form quickly and in succession?



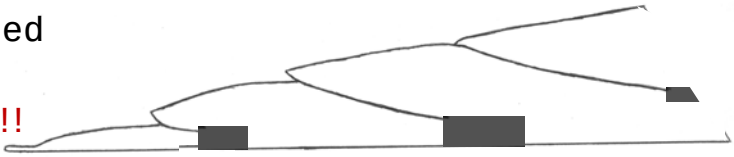
Why did this unit get this shape



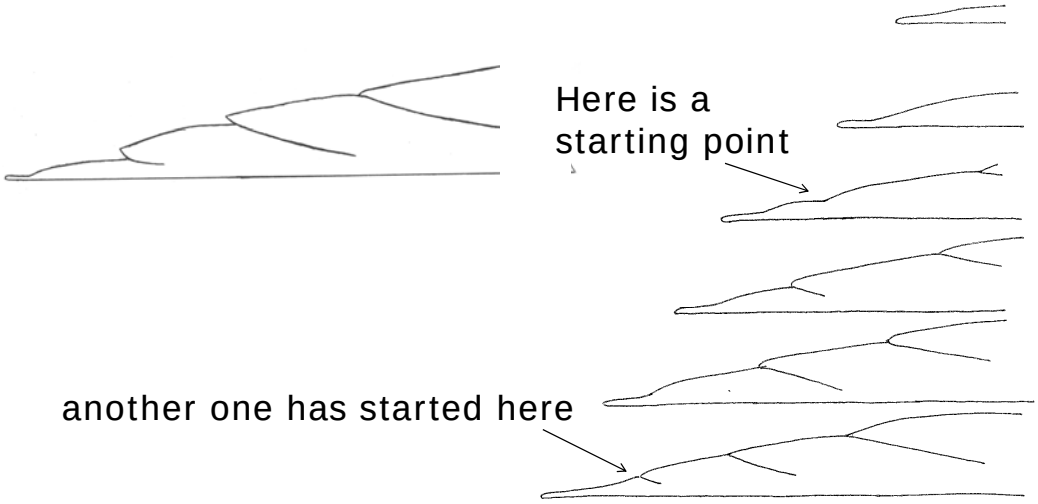


if this is the favoured interface.

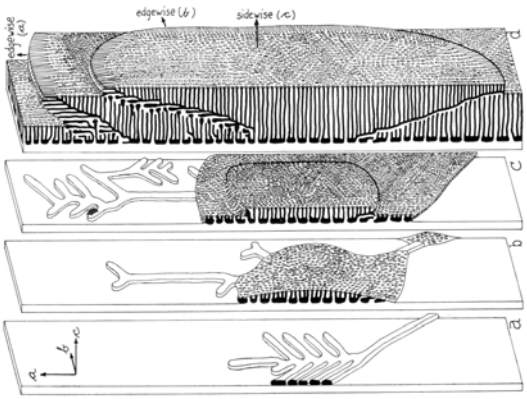
This is not realistic!!

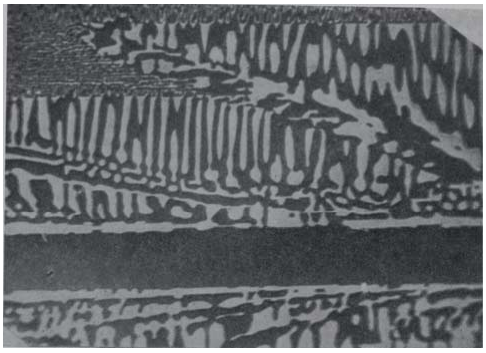


How can the subgrain boundaries form by a gradual growth?



Subunits in cast iron



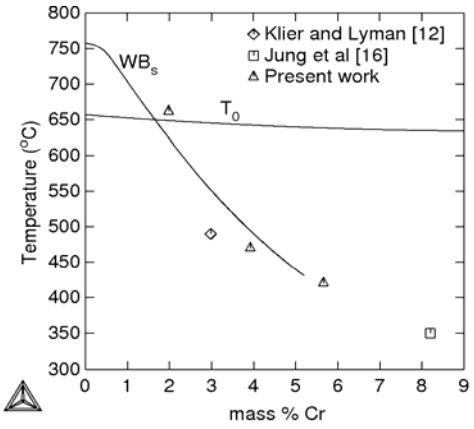


Hillert et al 1968 800x

How to test the diffusional hypothesis?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?
2. Has it been shown that carbides precipitate inside the bainitic ferrite?
3. Do carbides in tempered martensite and in lower bainite look the same?
4. Do subunits represent successive rapid steps where each one forms before the next one?
5. Can the diffusional hypothesis predict Ws and Bs?

Can a model based on the diffusional hypothesis predict the start temperature for Widmanstätten and bainitic ferrite?



Growth controlled by:

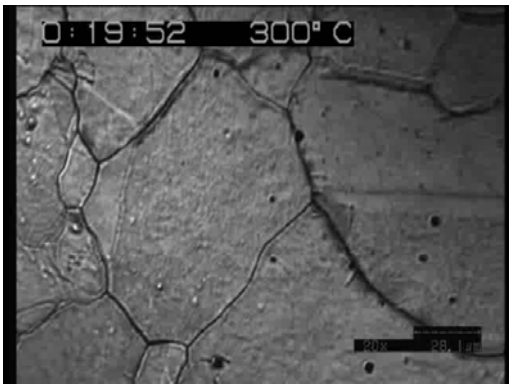
- Carbon diffusion
- Paraequilibrium conditions
- Constant thermodynamic barrier

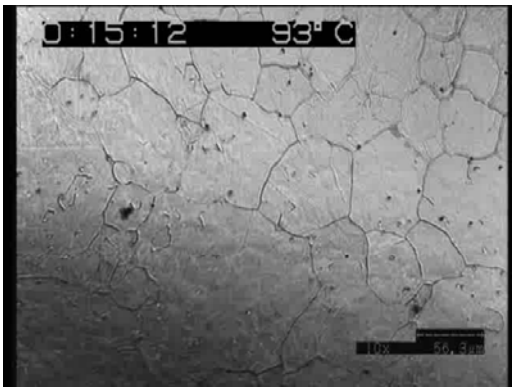
Hillert, Höglund and Ågren, 2004

How to test the diffusional hypothesis?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?
2. Has it been shown that carbides precipitate inside the bainitic ferrite?
3. Do carbides in tempered martensite and in lower bainite look the same?
4. Do subunits represent successive rapid steps where each one forms before the next one?
5. Can the diffusional hypothesis predict Ws and Bs?
6. Are the growth rates of bainitic ferrite and martensite of the same magnitude?

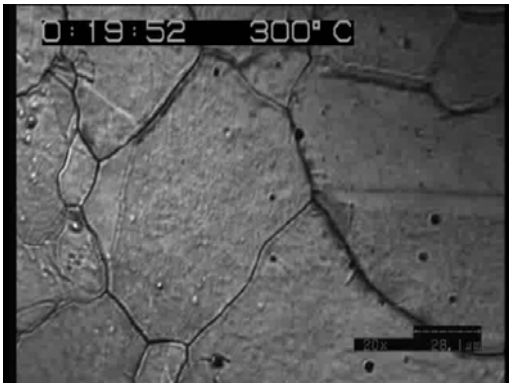
Are the growth rates of bainitic ferrite and martensite of the same magnitude?

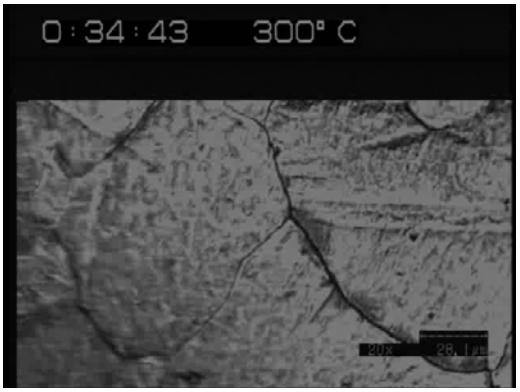




Kolmskog, Hedström, Borgenstam, 2010

Are the growth rates of bainitic ferrite and martensite of the same magnitude?





Kolmskog, Hedström, Borgenstam, 2010

How to test the diffusional hypothesis?

1. Is there an abrupt change of any property for Widmanstätten ferrite and bainite at Bs?
2. Has it been shown that carbides precipitate inside the bainitic ferrite?
3. Do carbides in tempered martensite and in lower bainite look the same?
4. Do subunits represent successive rapid steps where each one forms before the next one?
5. Can the diffusional hypothesis predict Ws and Bs?
6. Are the growth rates of bainitic ferrite and martensite of the same magnitude?
7. How is inverse bainite formed?

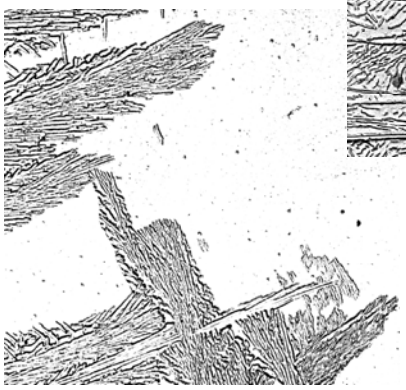
Can inverse bainite be explained by the diffusional hypothesis?

Symmetry in the Fe-C system.

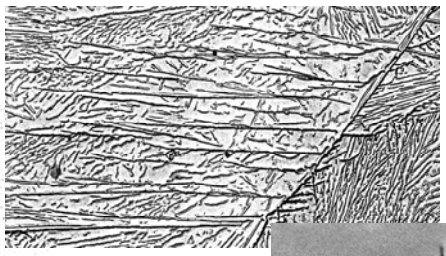
Bainite – eutectoid microstructure of ferrite and cementite with **ferrite as leading phase** in the main growth direction.

Inverse Bainite – eutectoid microstructure of ferrite and cementite with **cementite as leading phase** in the main growth direction

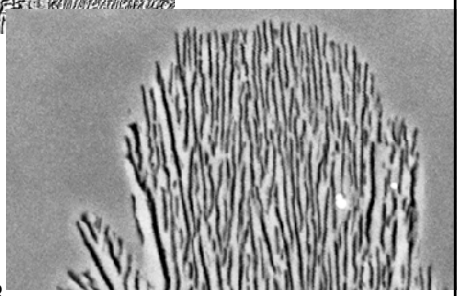
Inverse bainite in 1.65 w%C



900x



4000x



24000x

Modin and Modin, 1958
Borgenstam et al, 2010

Conclusions

- There is no difference between Widmanstätten and bainitic ferrite - must form by the same mechanism.
- Widmanstätten ferrite and bainite forms under diffusion of carbon.