Atoms in Bainite

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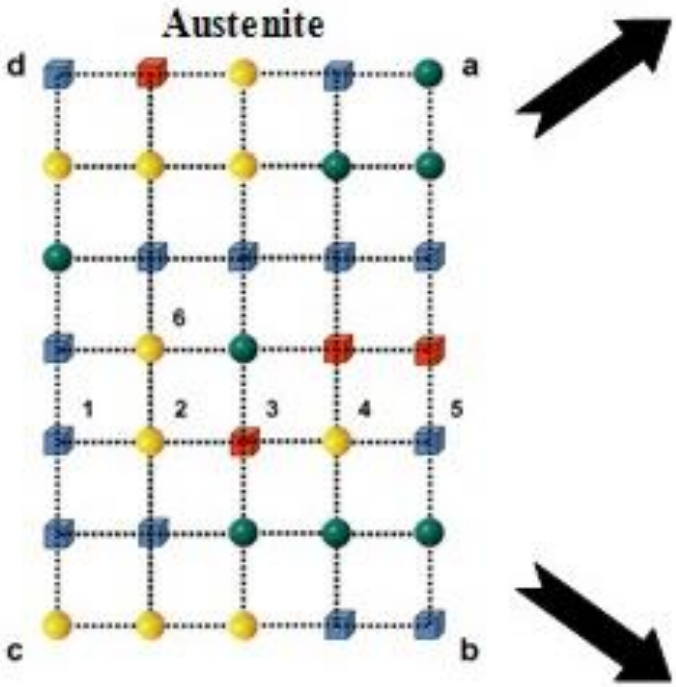
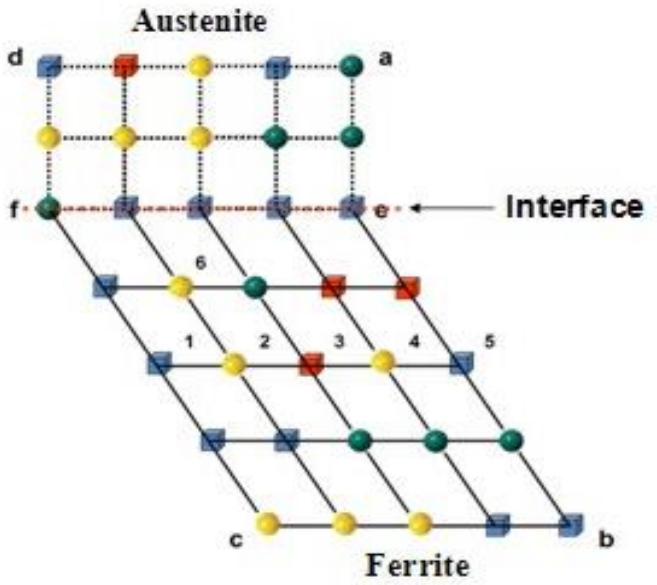
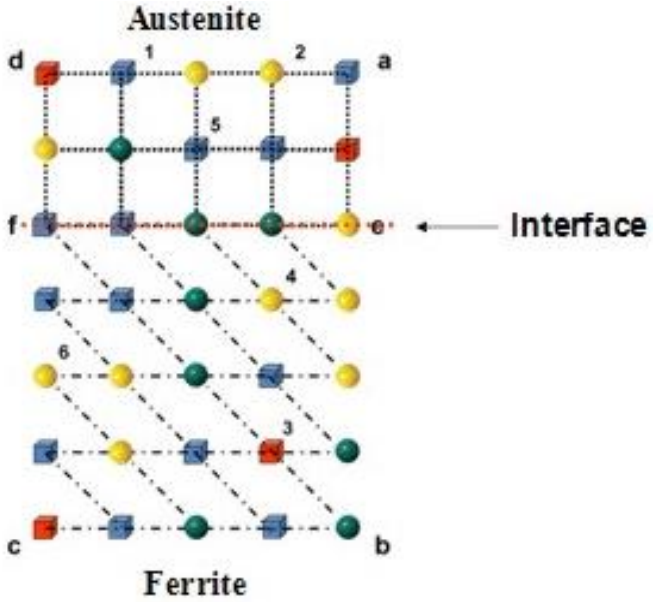
Bainite Transformation Mechanisms. 70 Years of Controversy

Displacive Theory

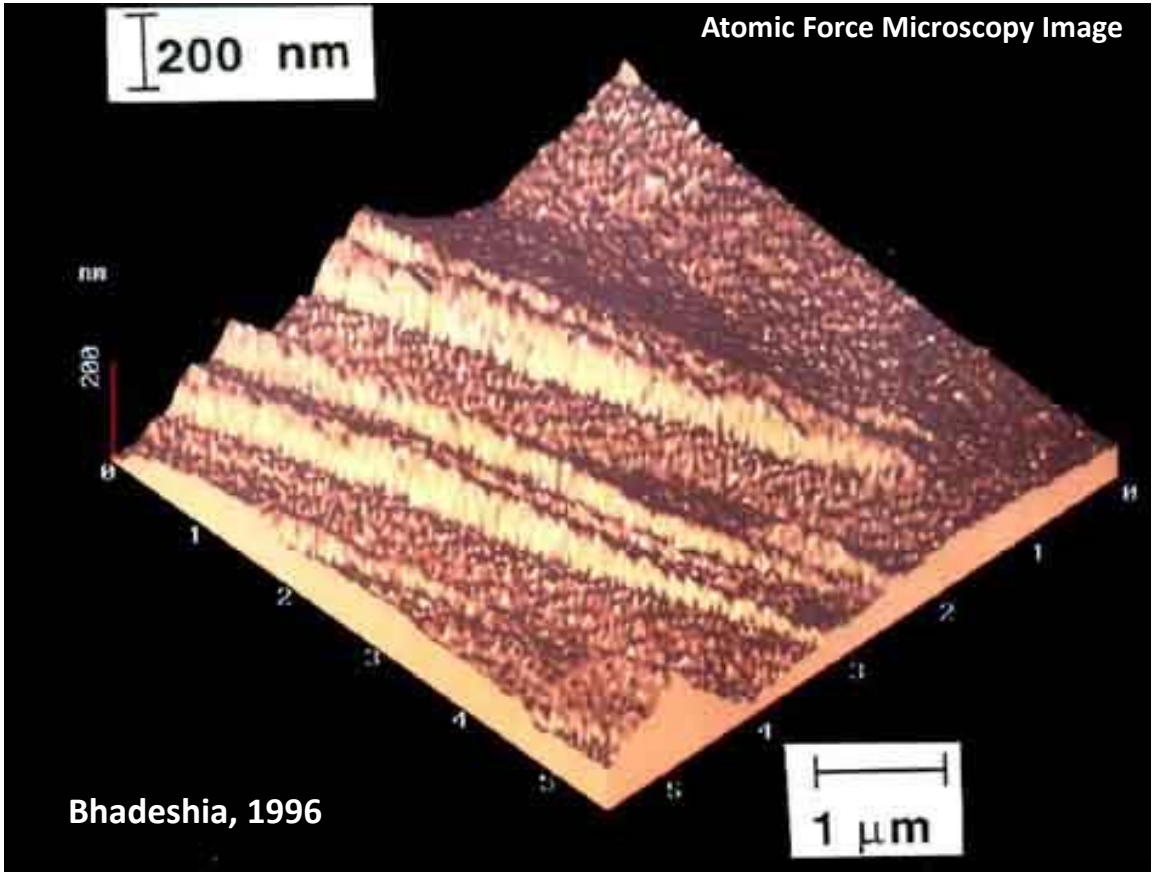




Reconstructive Theory

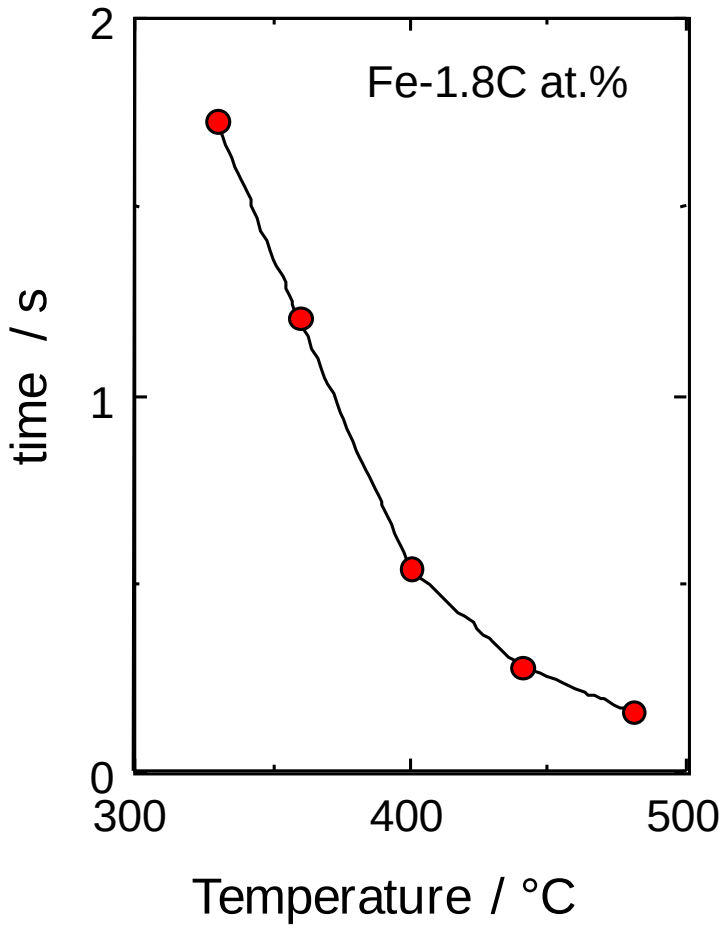


Bainite Transformation Mechanisms. Today Controversy



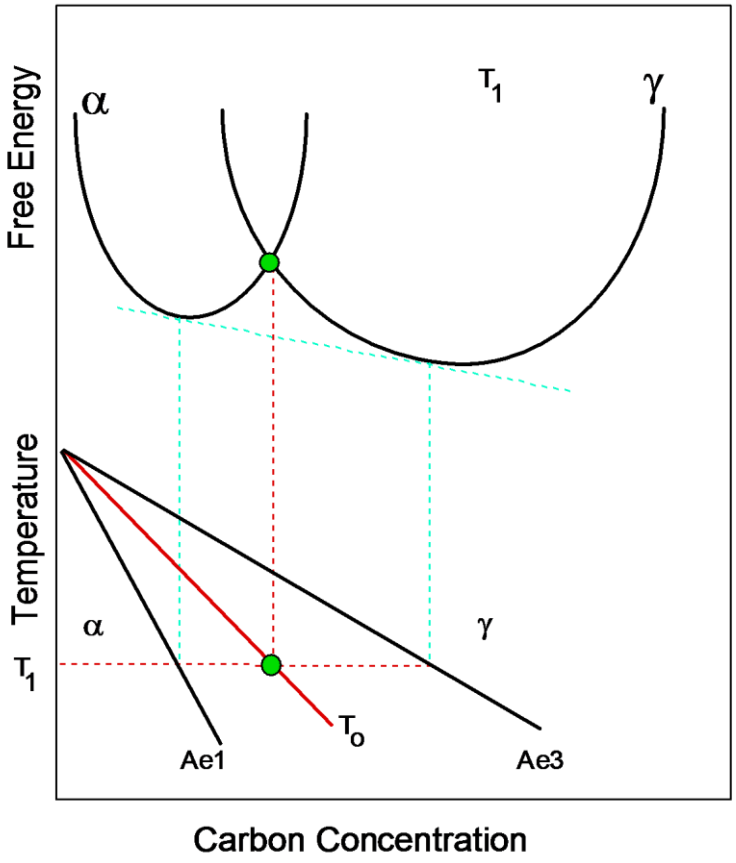
Today it is accepted that bainite grows with a displacive mechanism i.e. as plate-shaped (or lath-shaped) transformation product exhibiting an invariant plane strain surface relief effect.
But there is still much discussion on the diffusion or diffusionless nature of bainite.

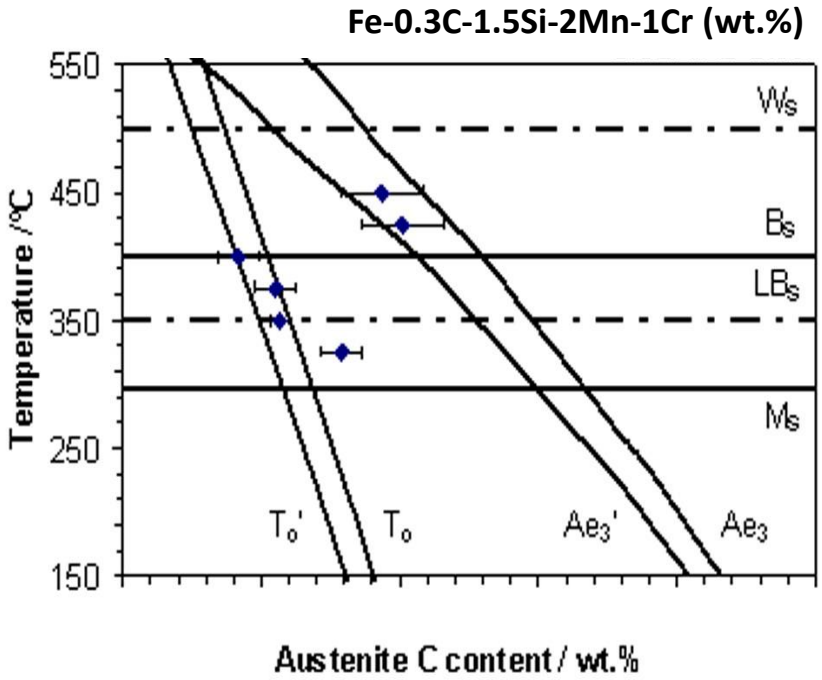
Bainite Transformation Mechanisms. Today Controversy



The criterion for distinguishing between these rival theories of bainite transformation is whether the newly formed bainitic ferrite has the **para-equilibrium carbon content** (~0.12 at.%) or if it is **supersaturated with carbon**.

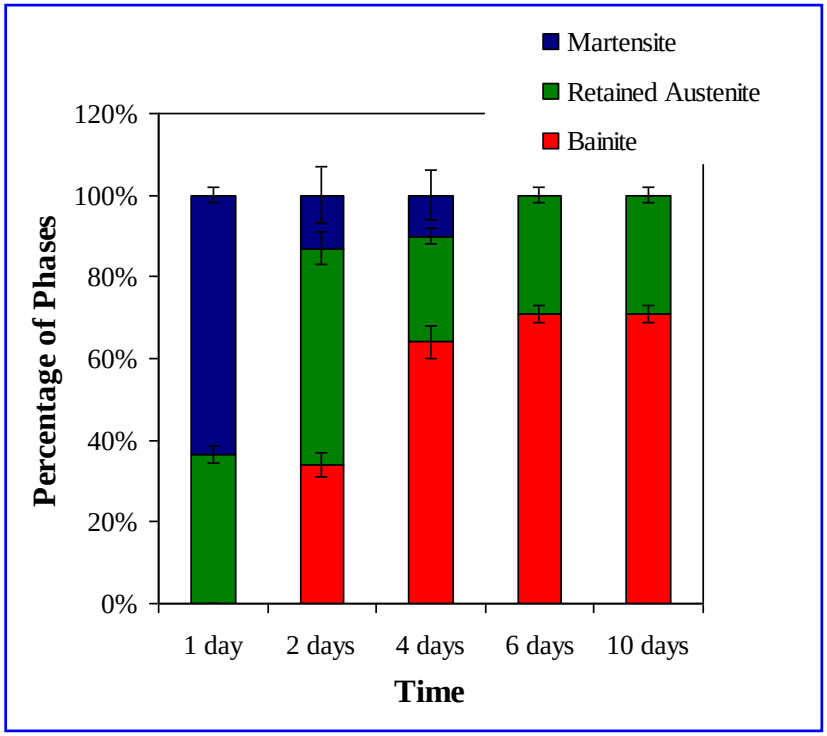
The Incomplete Reaction Phenomena

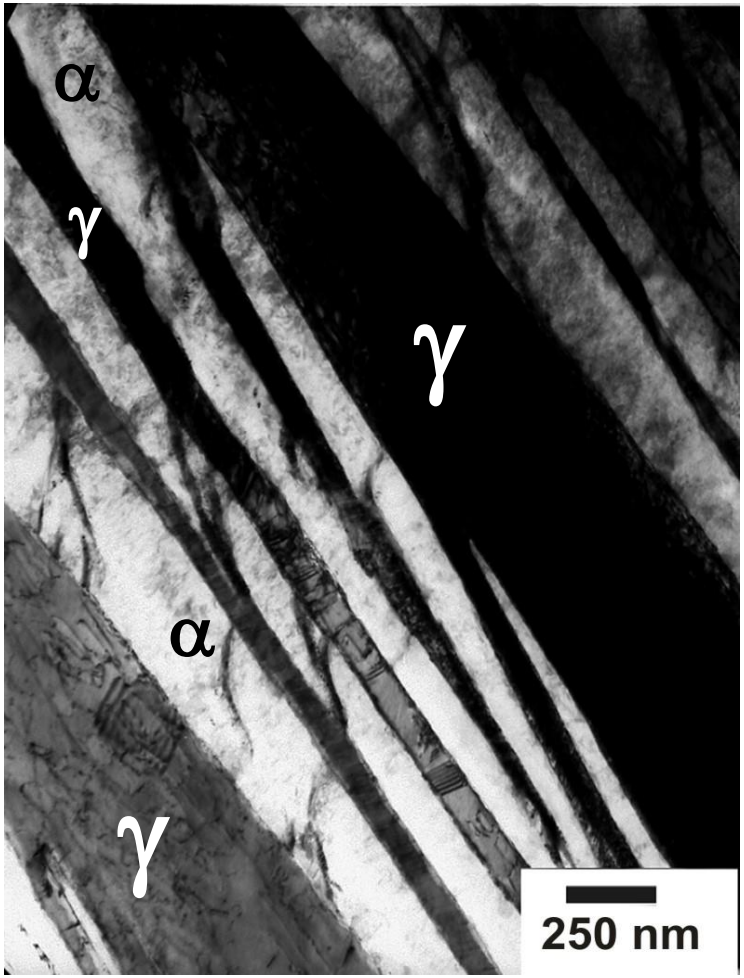




Carbon concentrations of the residual austenite confirming the incomplete reaction phenomenon i.e. **the T_o curve**, indicate that bainite initially forms having a full supersaturation of carbon.

Slow Bainite Transformation Kinetics



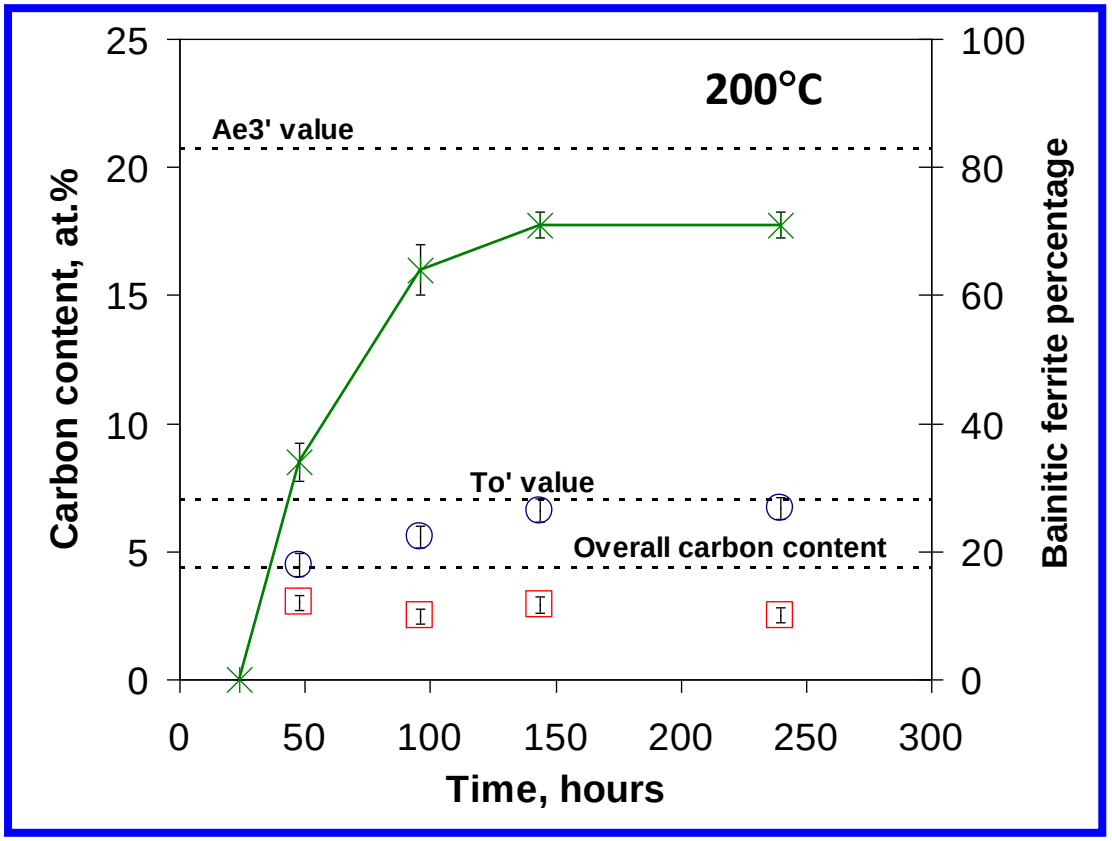


Fe-1C-1.5Si-2Mn-1Cr (wt.%) Steel

Transformation Temperature: 200ºC

Nanocrystalline ferrite (α) **and austenite** (γ).

Carbon Distribution during Transformation. XRD values



Carbon in bainitic ferrite

Carbon in austenite

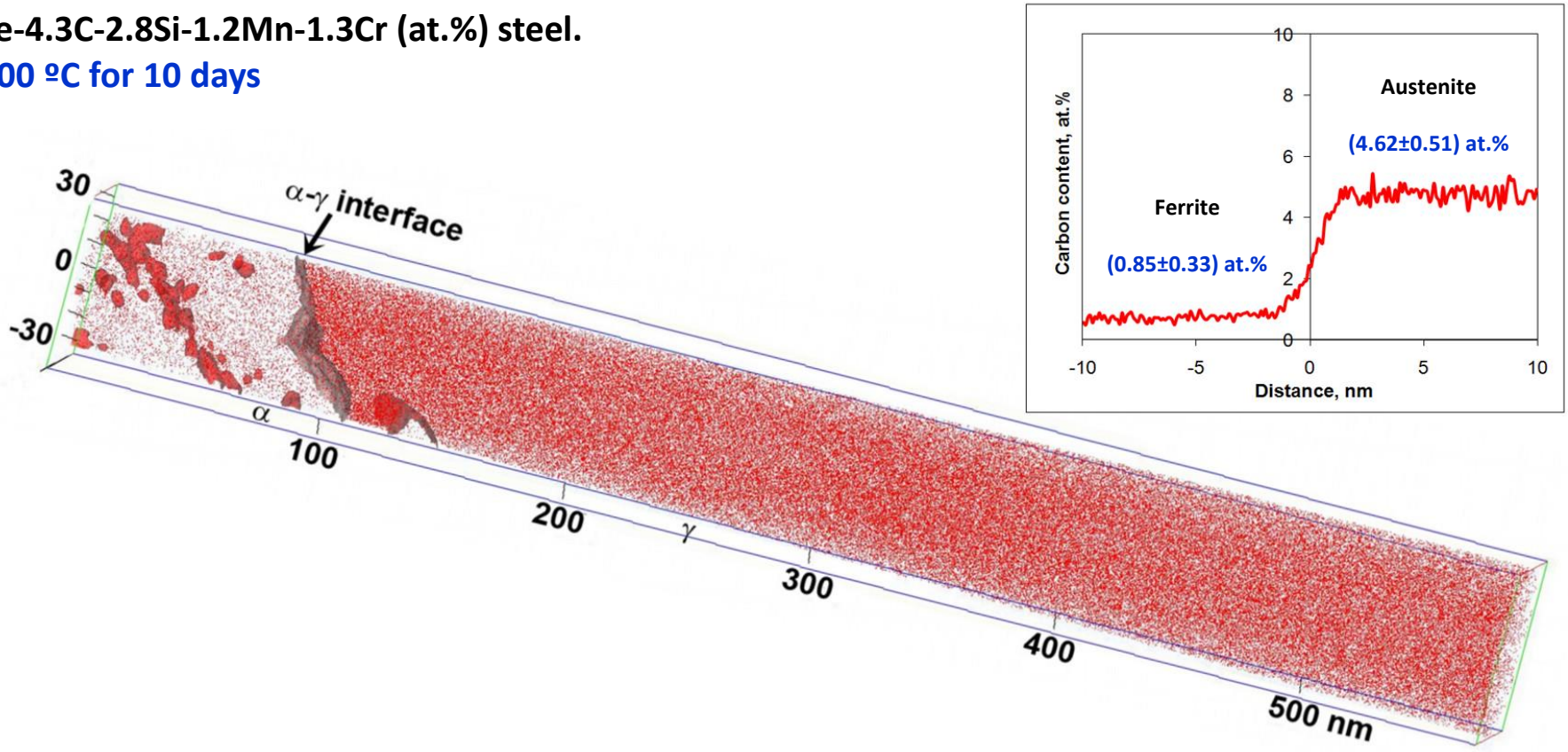
Bainitic ferrite percentage

XRD provides **an average estimate** of the carbon in the ferrite matrix and all carbon-enriched regions, such as dislocations and boundaries.

Ferrite / Austenite at the Atomic Scale

Fe-4.3C-2.8Si-1.2Mn-1.3Cr (at.%) steel.

200 ºC for 10 days

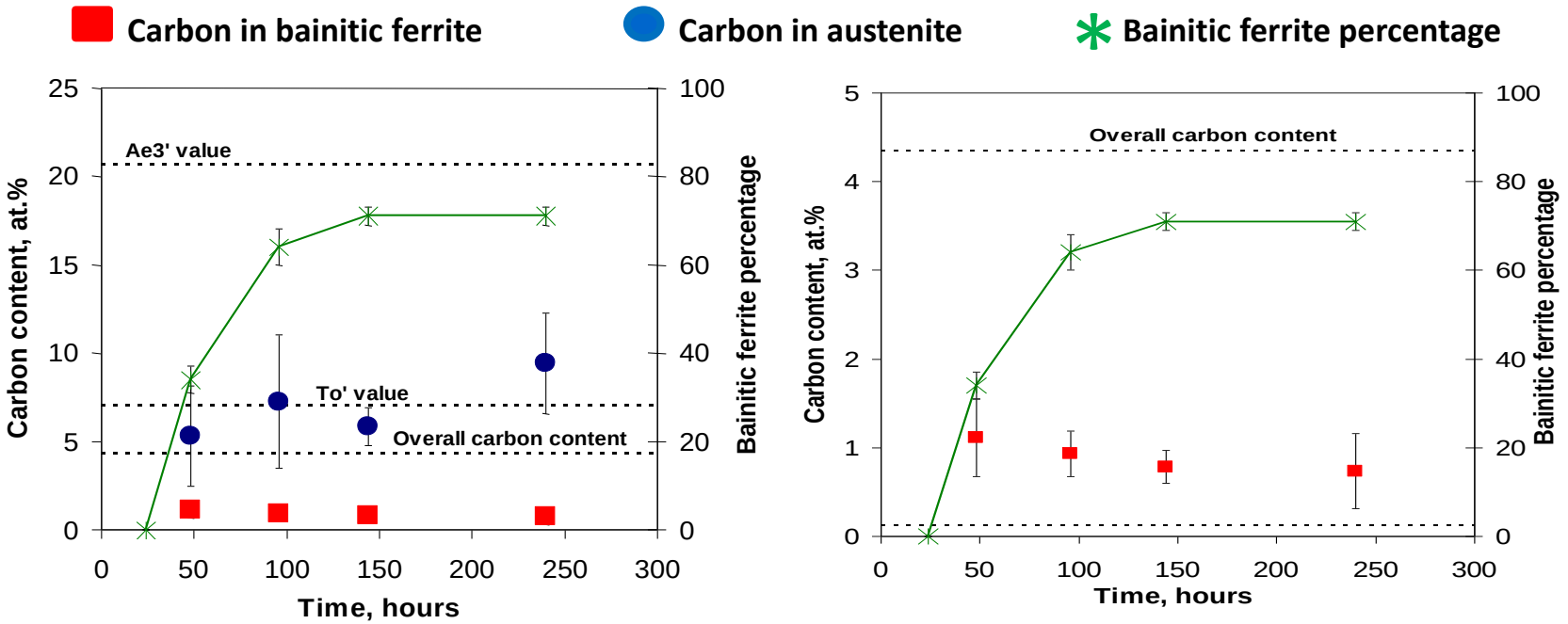


Atom Probe Tomography

Carbon content of the ferrite is higher than that expected from paraequilibrium with austenite (0.12 at.%).

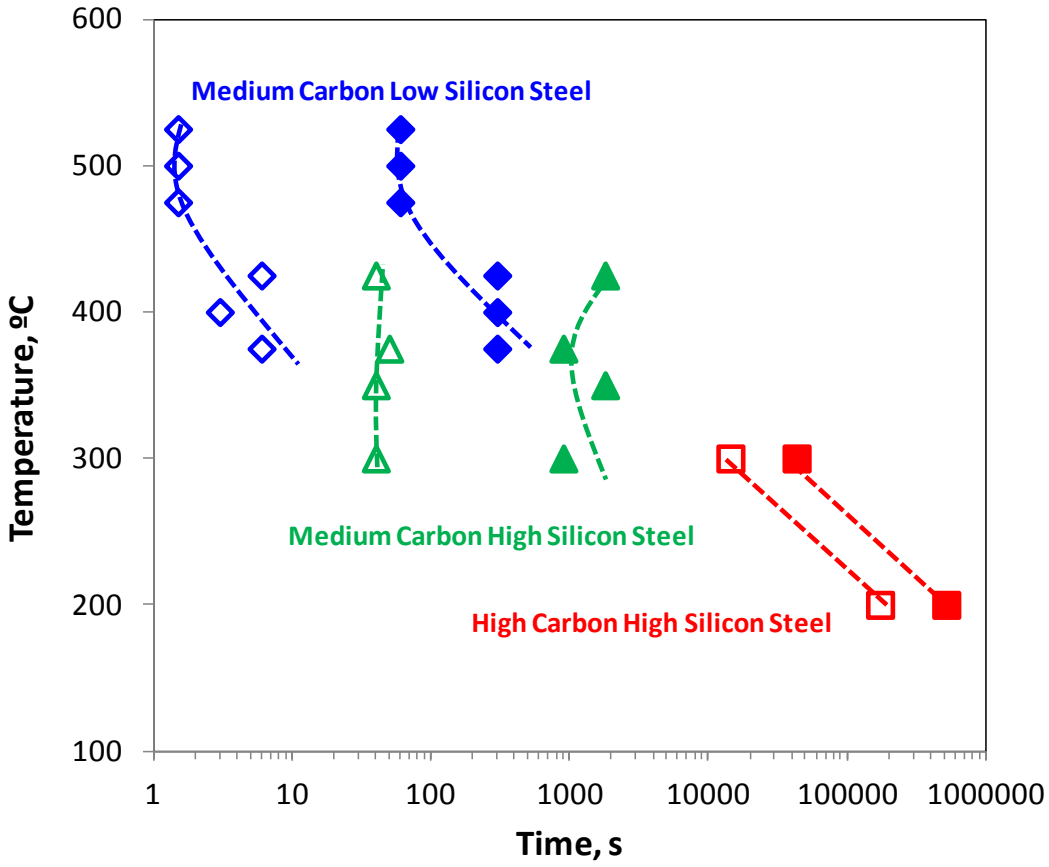
Carbon Distribution during Transformation. APT Results

200°C

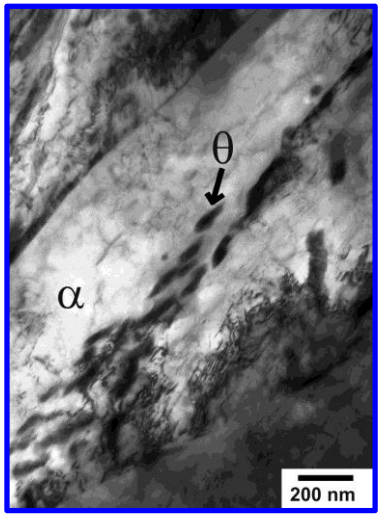


Bainitic **ferrite grows supersaturated** with carbon consistently with a **diffusionless growth mechanism**. However, it seems natural to believe that **trapping of carbon in the growing ferrite require faster kinetics** than those observed experimentally.

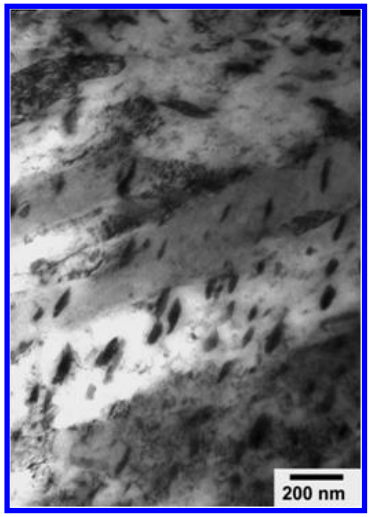
Reaction Rate and Carbon Supersaturation



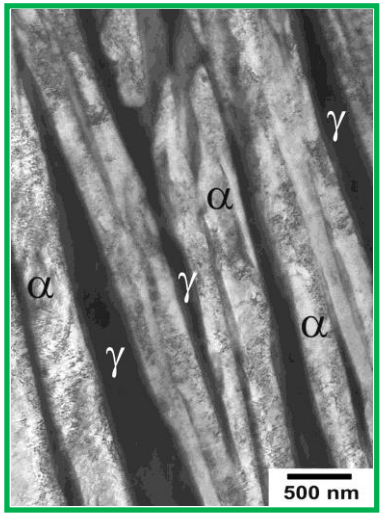
500ºC



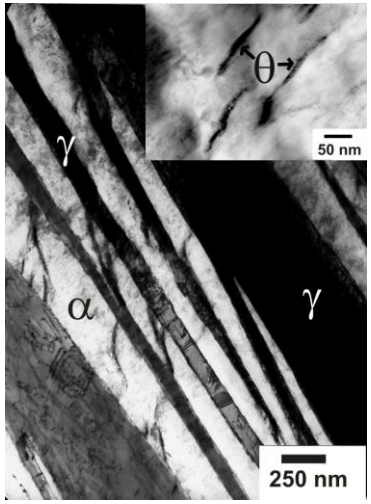
375ºC



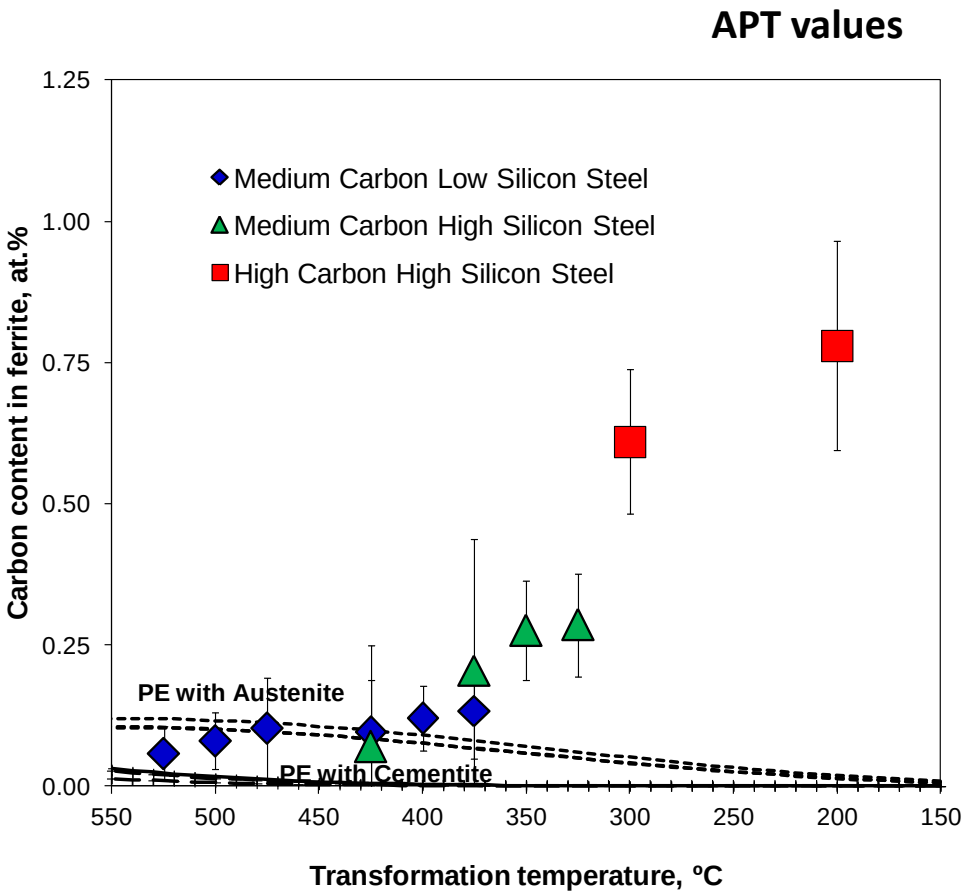
425ºC



200ºC



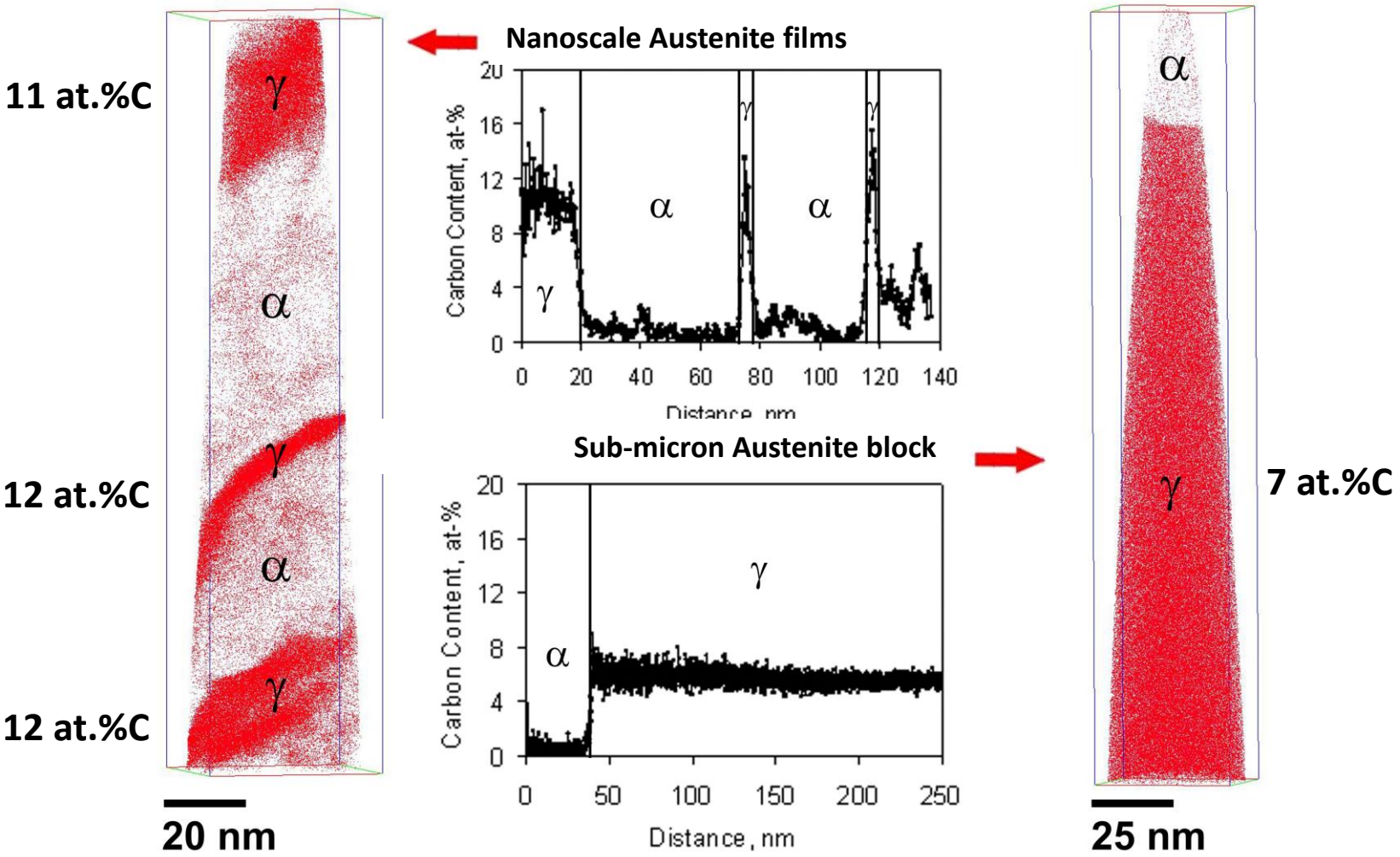
Temperature Dependence of Carbon Supersaturation



The bainitic ferrite grows supersaturated with carbon independently of the transformation temperature and the overall reaction rate. As the transformation temperature is increased, carbon diffusion is enhanced providing an opportunity for the decarburization of the supersaturated ferrite soon after the growth event.

Partitioning of Carbon into the Residual Austenite

High Carbon High Silicon Steel **200 °C**



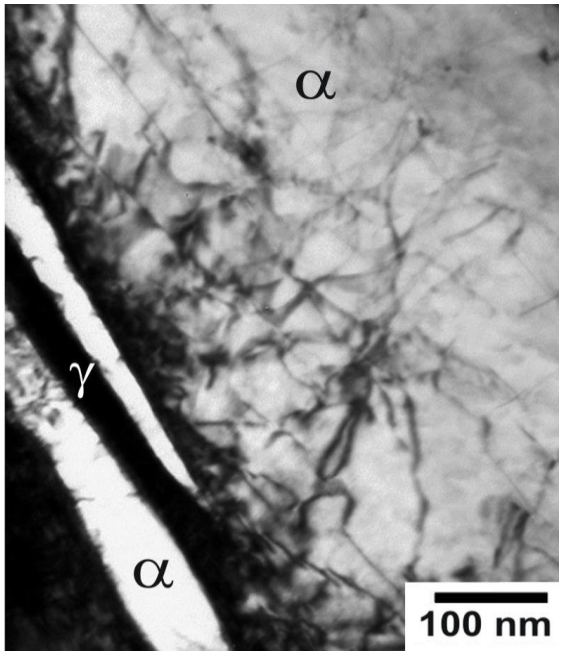
Austenite films entrapped between neighboring subunits of bainitic ferrite

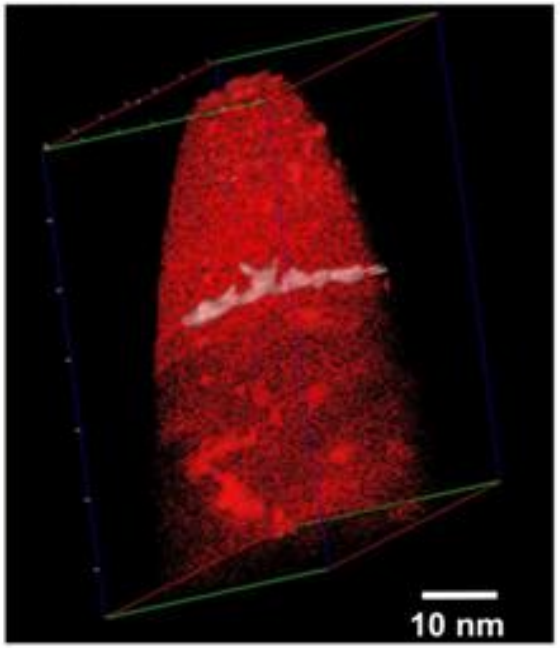
Blocks of residual austenite located between the sheaves of bainite

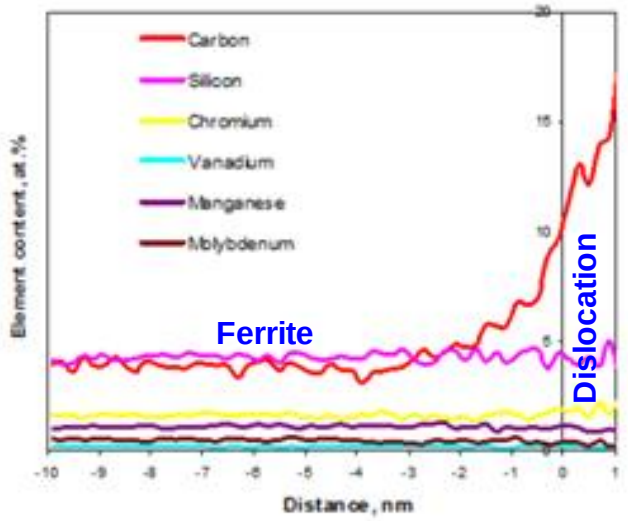
Segregation of Carbon Atoms to Dislocations

High Carbon High Silicon Steel

200 °C





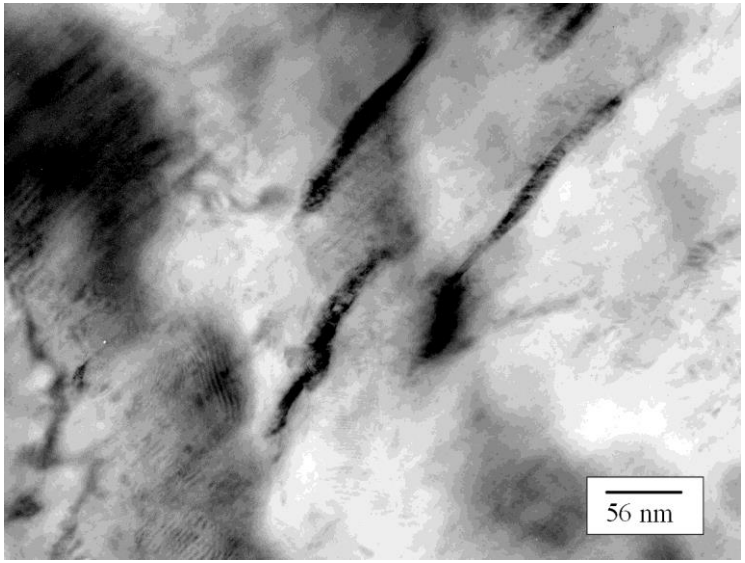


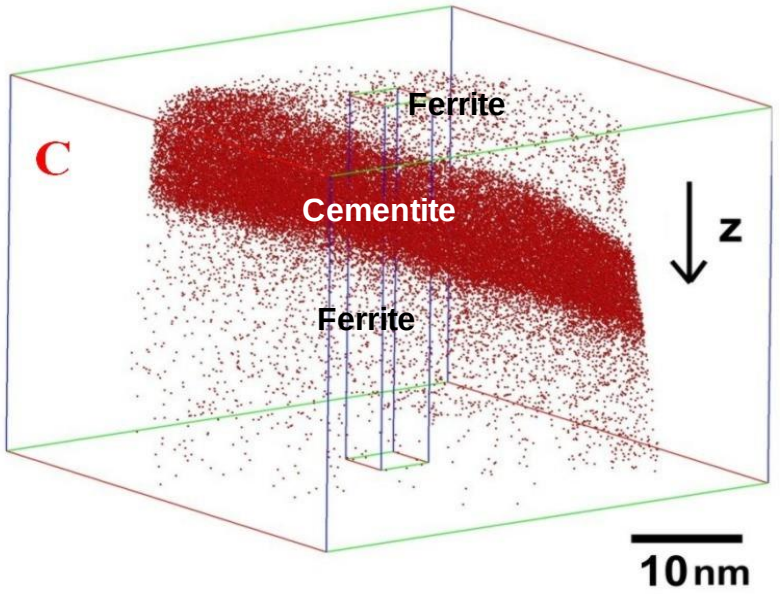
Dislocations are created when the shape deformation accompanying bainite growth is accommodated by plastic relaxation of the surrounding austenite.

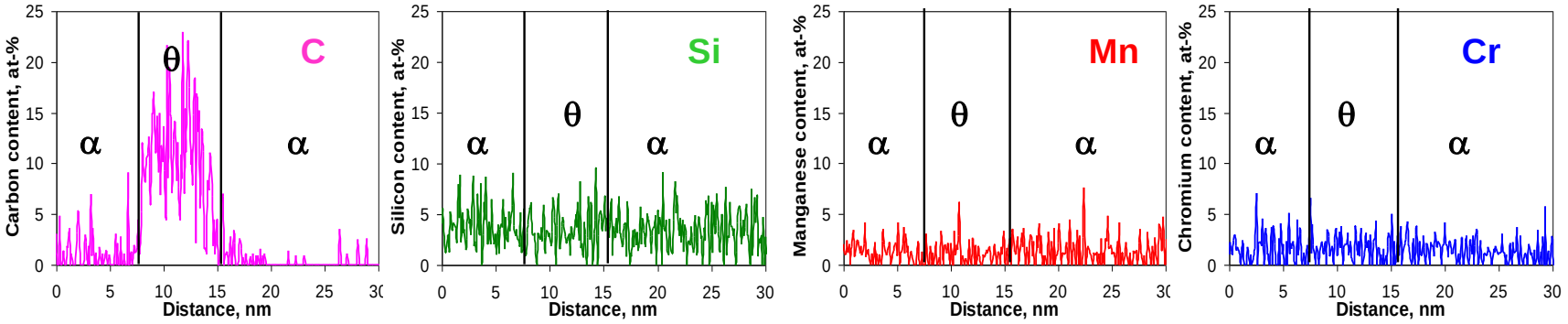
Carbide Precipitation in Ferrite

High Carbon High Silicon Steel

200 °C







Bainitic carbides nucleates and grows within supersaturated ferrite in a process identical to the tempering of martensite

Conclusions

Atom-probe tomography results provided strong evidence that bainitic ferrite grows without any diffusion of carbon, and carbon supersaturation is subsequently relieved by partitioning to austenite, or through carbide precipitation.

DISPLACIVE AND DIFFUSIONLESS growth mechanisms