Formation kinetics of acicular/bainitic ferrites in HSLA steel

—Role of dissolution and precipitation of Nb

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Outline

- Introduction/motivation
- Experimental observations
- Kinetic analyses
- Conclusions

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What is HSLA steels?

High Strength Low Alloy (HSLA) steels constitute an important category of steels estimated to be around 12% of total world steel production.

HSLA steel typically contains 0.07 to 0.12% **carbon**, up to 2% **manganese**, minor addition of **niobium**, **vanadium** and **titanium** (usually max. 0.1%) in various combinations.

e.g. The chemical composition of **X65** piping steels (in weight)

C	Mn	Si	Ni	Cr	Mo	Cu	V	Al	Nb	Ti
0.09	1.29	0.29	0.15	0.06	0.18	0.13	0.05	0.034	0.03	0.001

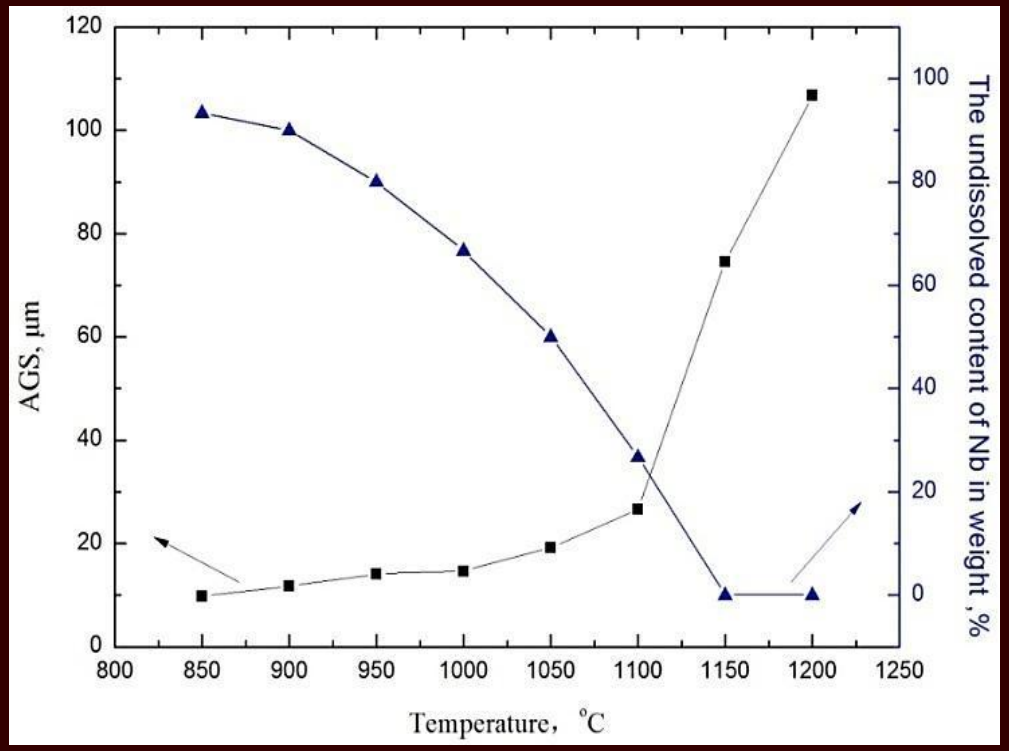
HSLA steel can be found in these applications:

Tubular
Components
Heavy
Equipment
……

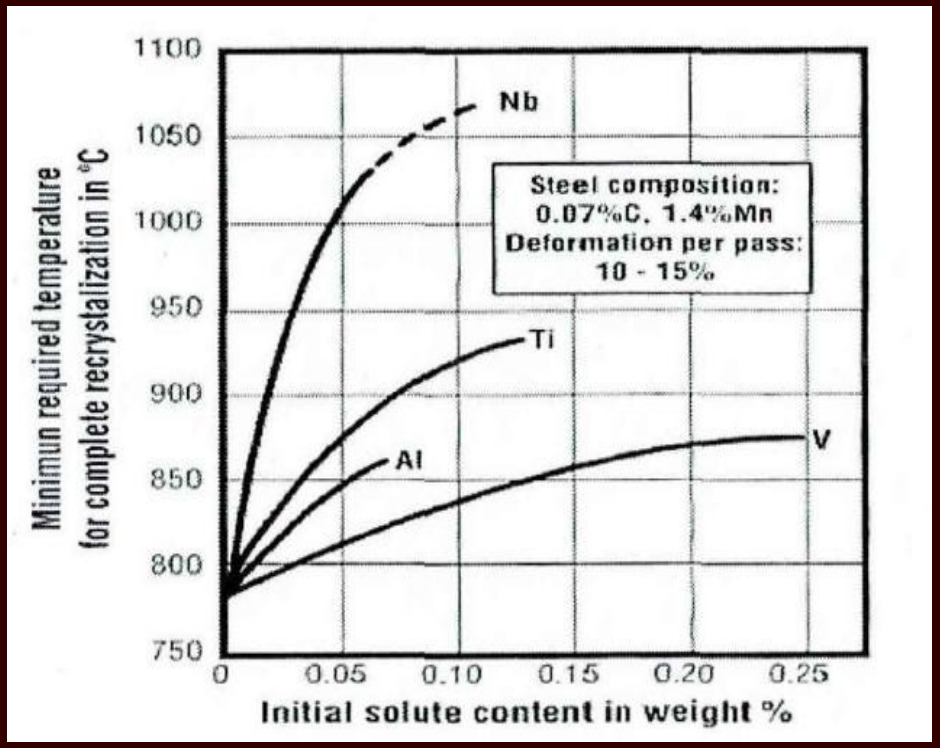
The role of Nb in pipeline steel

1. Refine the grains 2. Retard austenite recrystallization

3. Influence γ→α transformation?

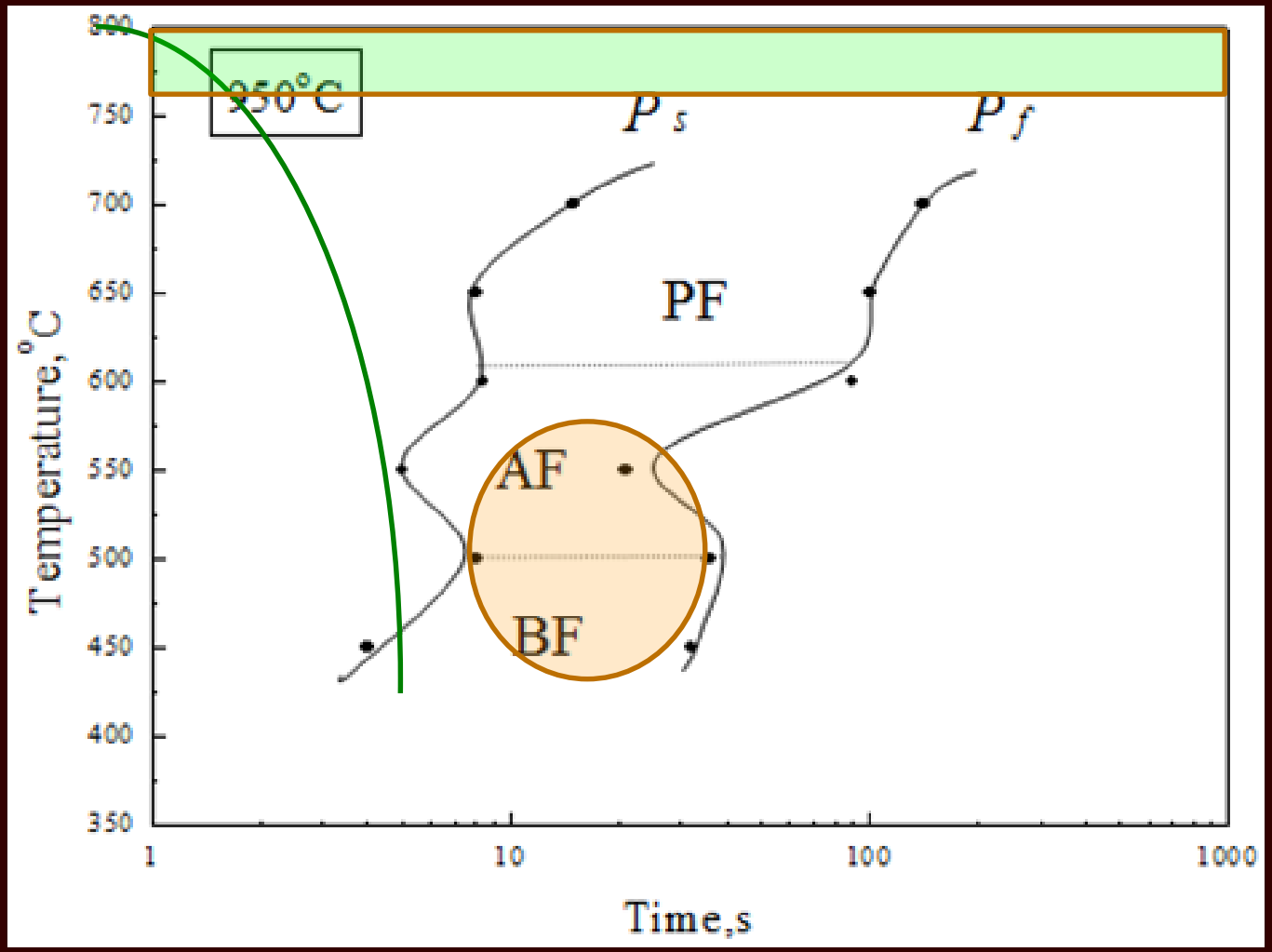


The relation of Austenite grain sizes and the undissolved content of Nb.



Retardation of recrystallization by microalloying elements.

Determined TTT curve of the X65 piping steel



Products:

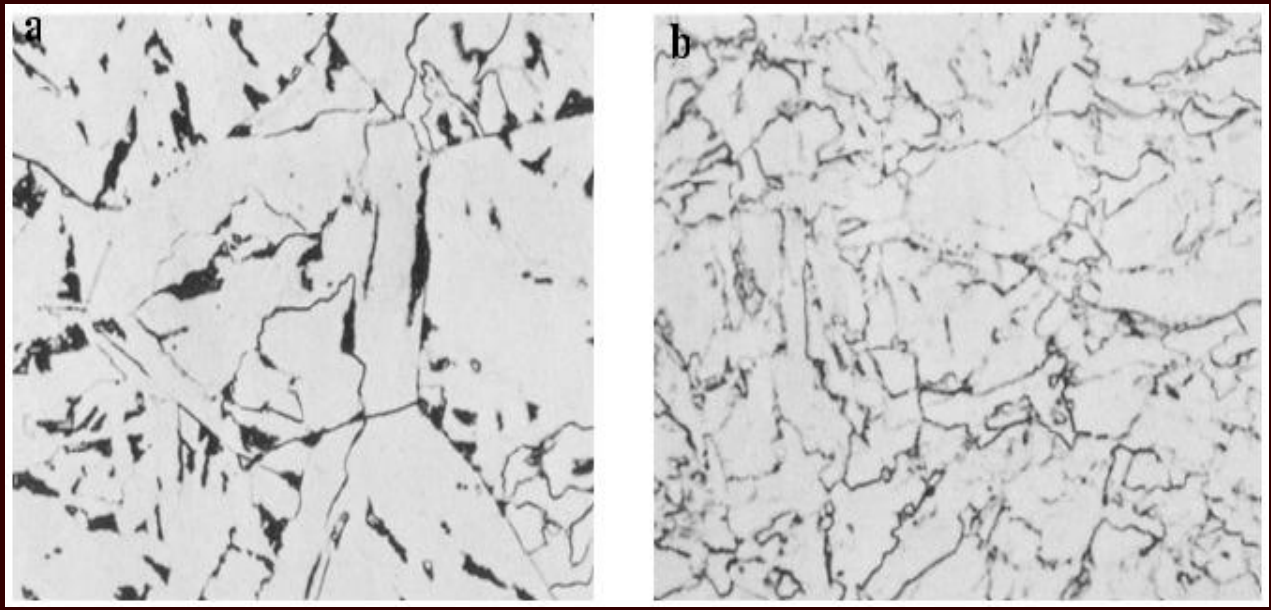
Polygonal ferrite (PF)

Acicular ferrite (AF)

Bainite ferrite (BF)

The acicular ferrite (AF) is an ideal structure for pipeline steel

It is commonly defined as a highly sub-structured non-equiaxed phase that forms during continuous cooling by a mixed diffusion and shear transformation mode at a temperature range slightly higher than that of upper bainite.*



*Y.E Smith, A.P. Coldren. Toward improved ductility and toughness.1972.

Question to be answered:

☞ **What's the effect of Nb on the formation of AF?**

☞ **How would we tailor the AF or BF structures by cotrolling the state of NbC?**

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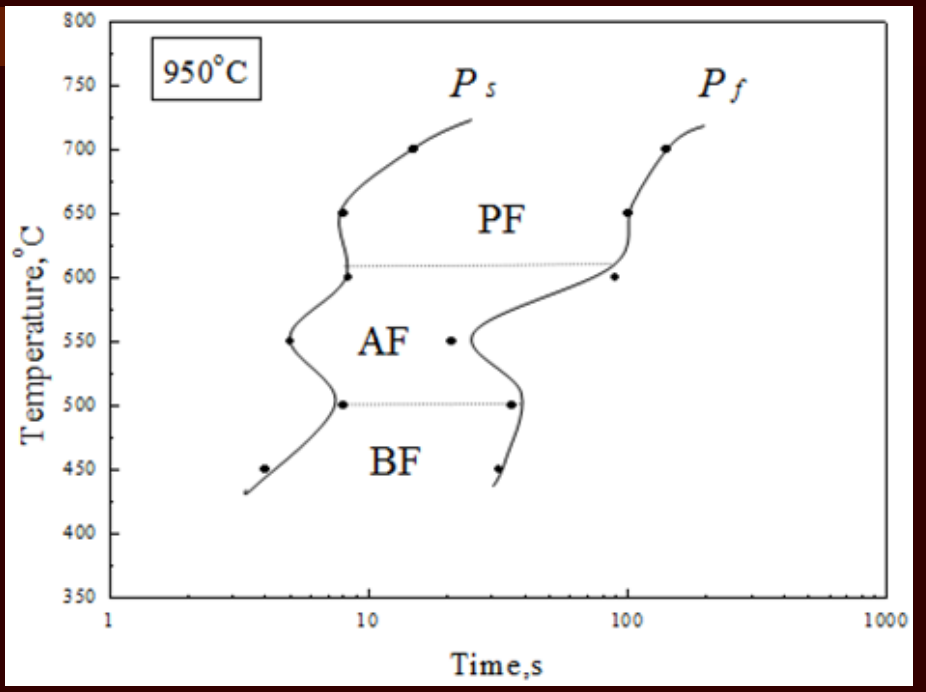
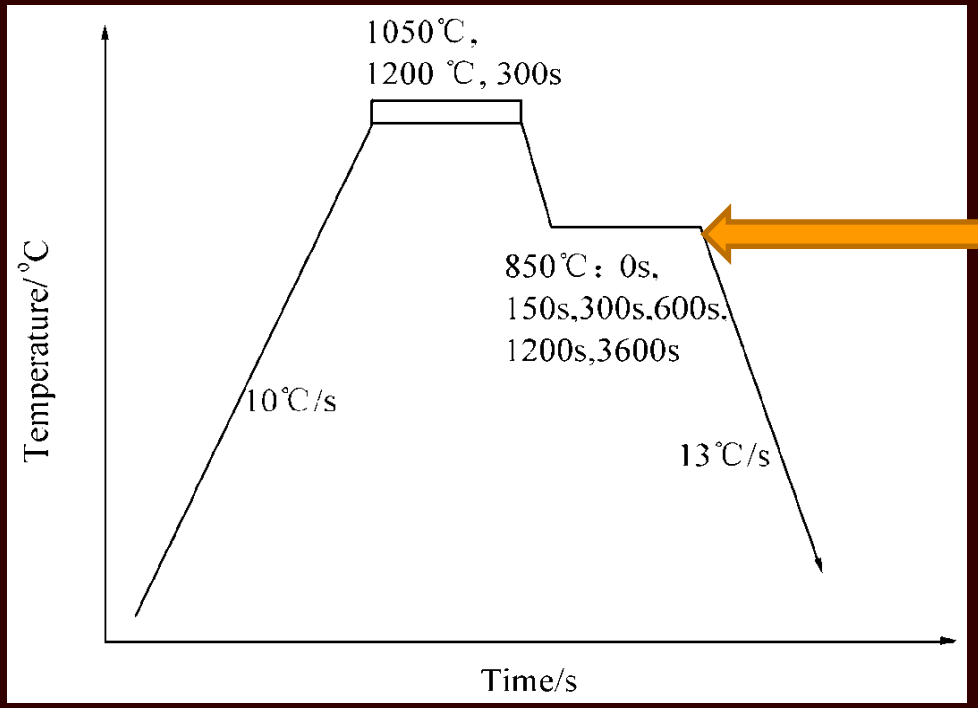
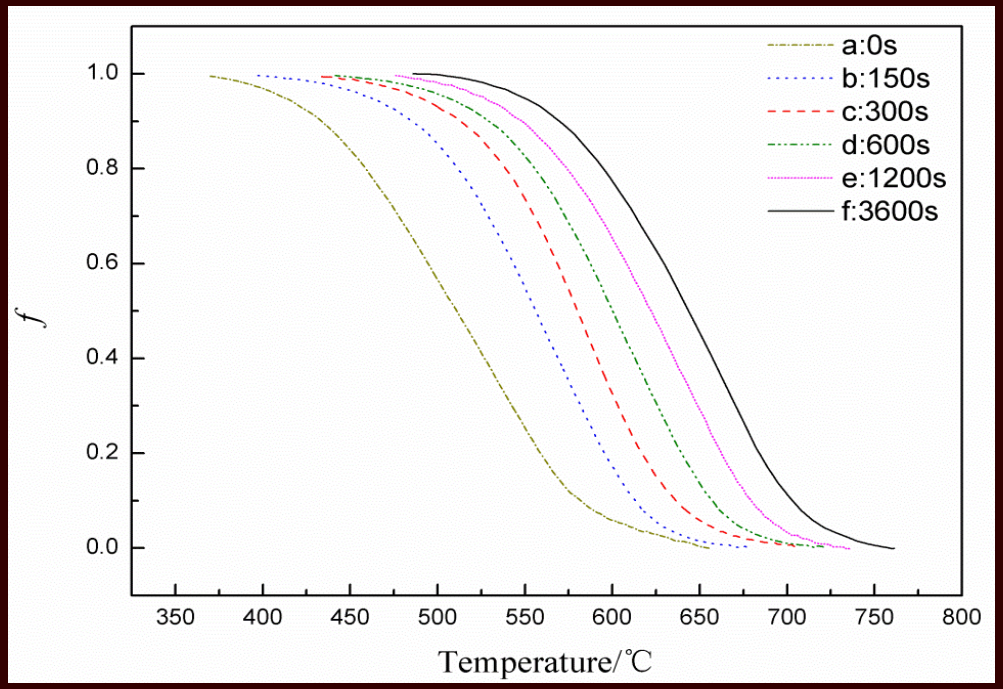




850 degree is a temperature at which no ferrite forms with large amount of NbC precipitates.

Schematic diagram of the adopted heat treatment program for the X65 steel.

Determination of the A_{r3} and A_{r1} Temperatures from the measured dilation curves



The transformed fraction as a function of time during cooling for specimens holding at 850℃ for various durations.

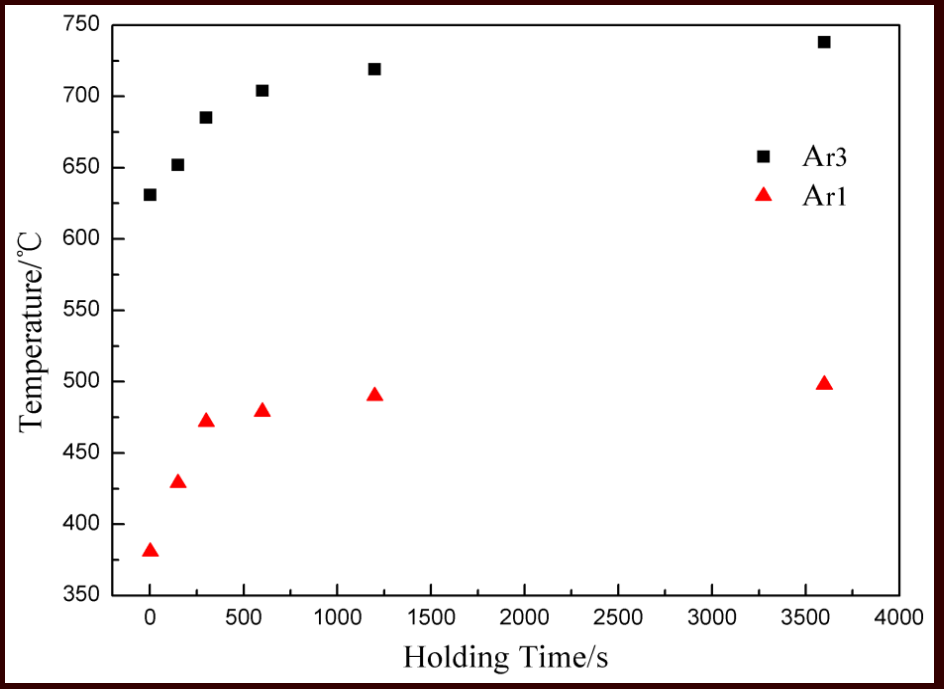
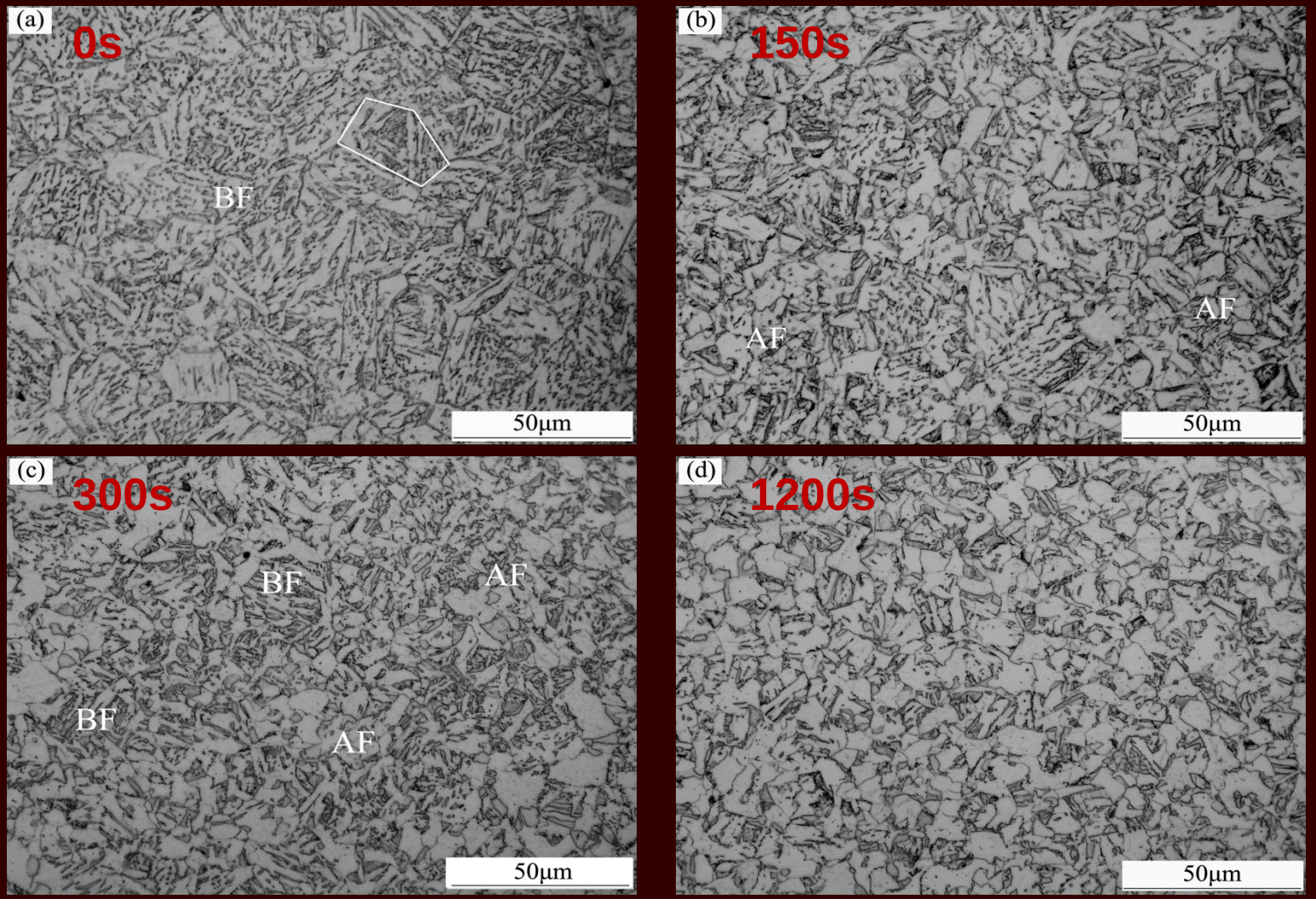
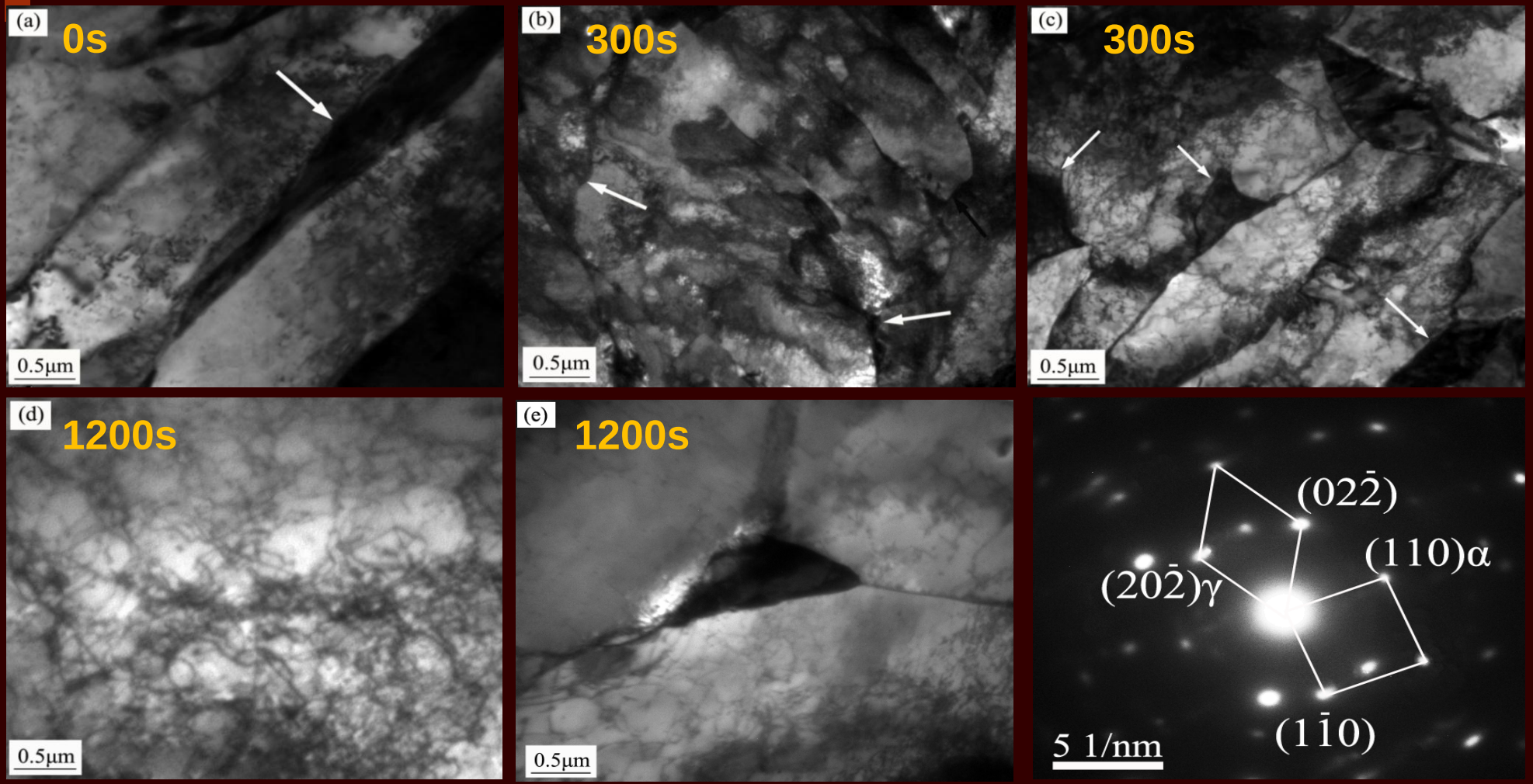


Diagram of the A_{r1} and A_{r3} temperatures tendency measured after austenitizing at 1050℃.

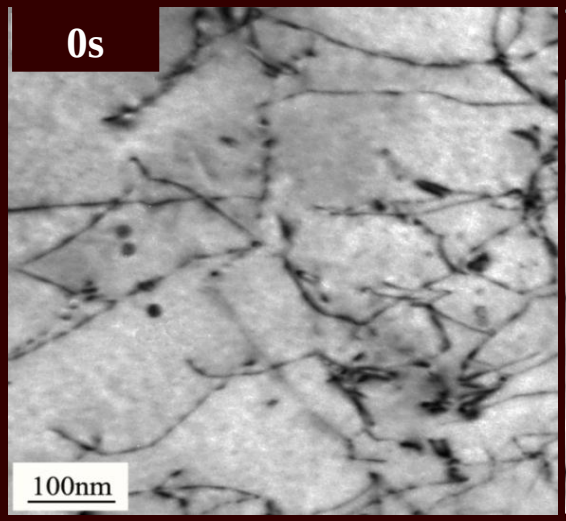


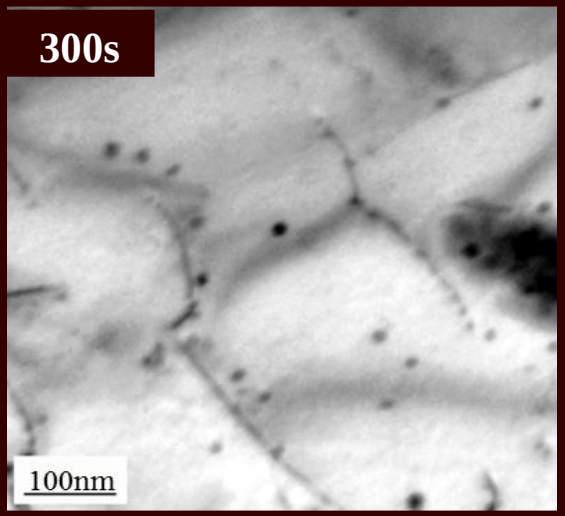
Optical micrographs of specimens austenitized at 1050℃ followed by isothermally holding at 850℃ for different durations

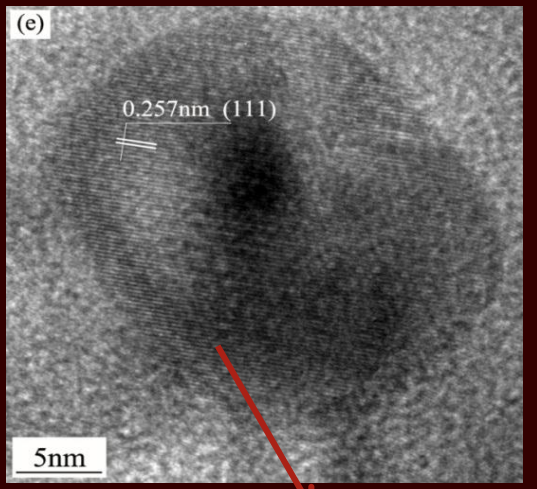


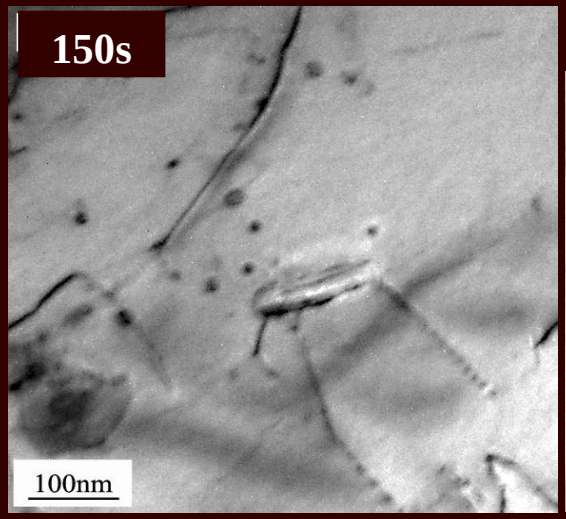
TEM images of specimens isothermally held at 850℃ for different time (a) BF with M/A film; (b) AF/BF dual-phase; (c, e) M/A island; and (d) dislocations.

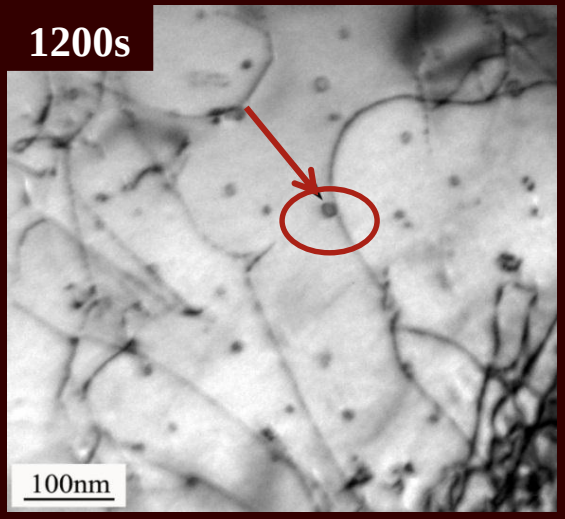
TEM images of NbC precipitates in specimens isothermally held for various durations

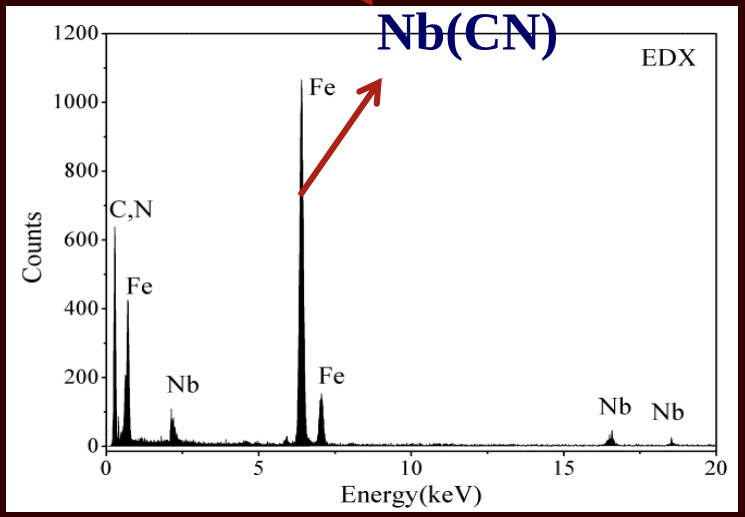




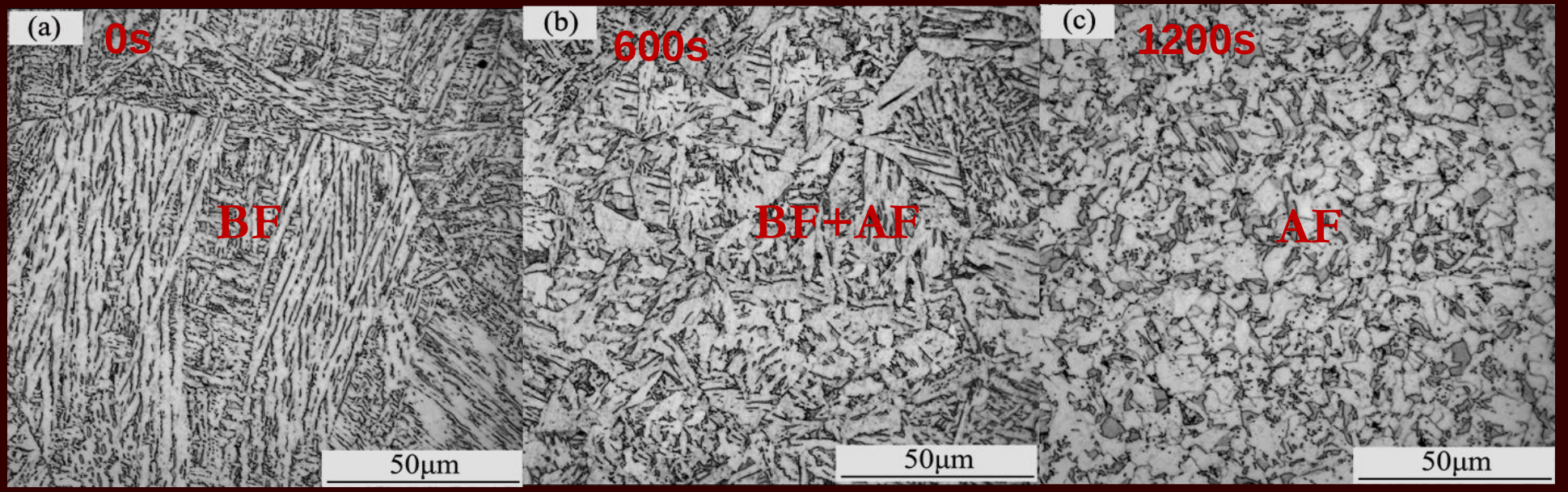








The microstructural evolution austenitized at 1200 degree is in agreement with the specimen austenitized at 1050 degree.



Optical micrographs of X65 steel specimens austenitized at 1200℃ followed by isothermally holding at 850℃ for different durations

Dissolved, undissolved Nb contents under different holding time at 850℃ measured by ICP-AES

Austenitized temperature	Holding time at 850 ºC	Dissolved Nb (wt%)	Undissolved Nb (wt%)	Precipitation percent of NbC
1050 ºC	0s	0.014	0.016	53.6%
	300s	0.011	0.019	61.9%
	1200s	0.004	0.026	87.4%
1200 ºC	0s	0.024	0.006	18.7%
	600s	0.012	0.018	59.1%
	1200s	0.008	0.022	72.8%

The amount of NbC precipitates increases with the increase of isothermal holding at 850℃, the state of Nb in γ adjusted the subsequent kinetic process.

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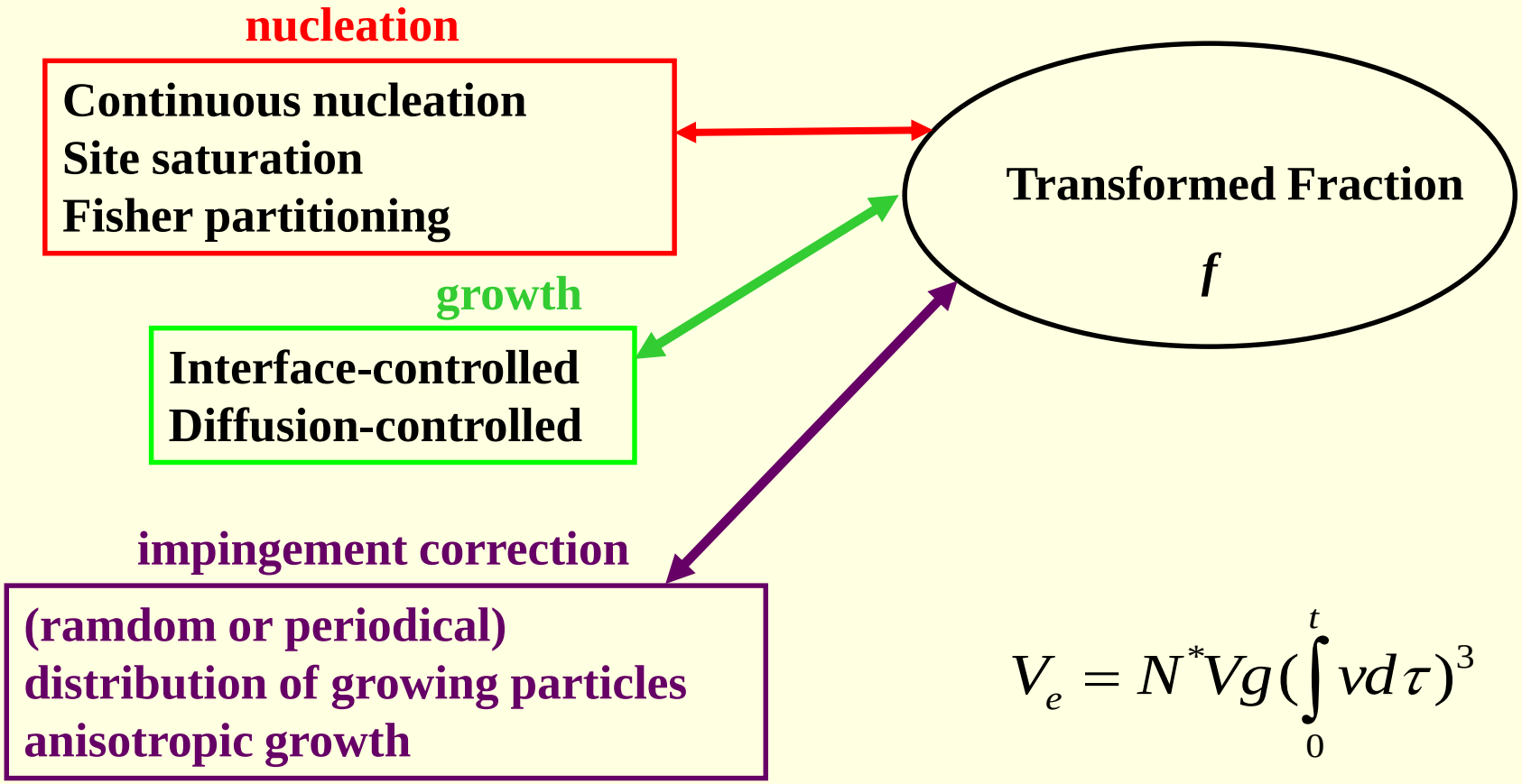
General Modular Transformation Model*



$$V_e = N^* V g \left(\int_0^t v d\tau\right)^3$$

- F Liu, F Sommer, C Bos, E J Mittemeijer. Inter Mater Rev 2007, 52: 193.

Analytical Modular Phase Transformation Model

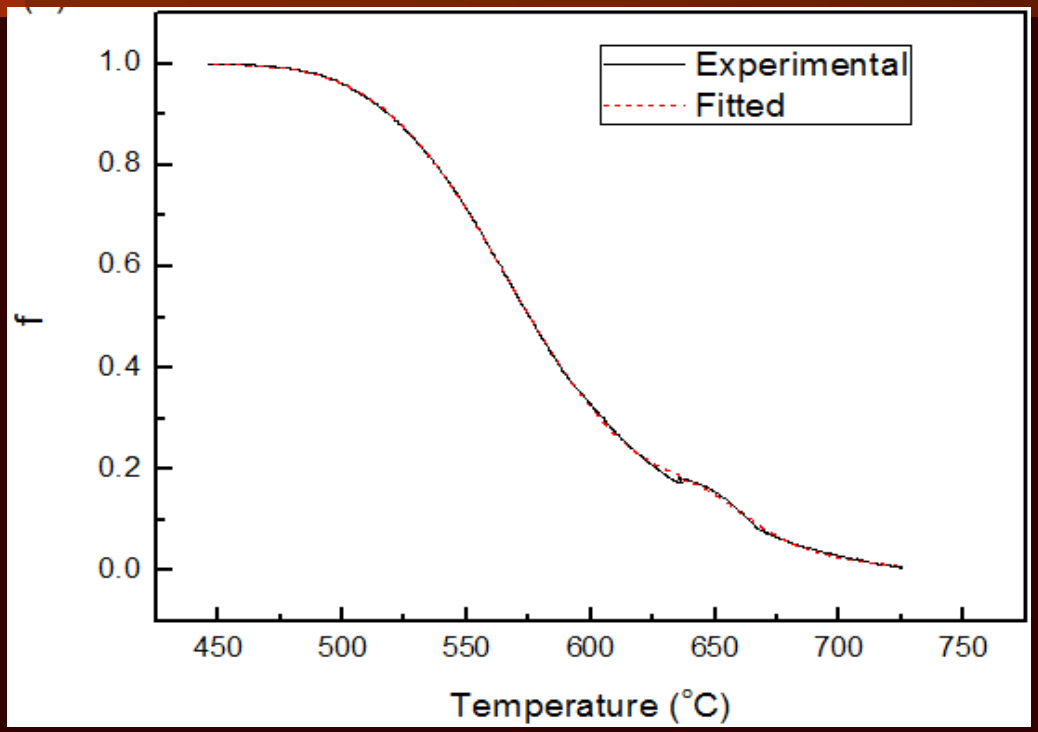
FORMATION OF ACICULAR FERRITE

Nucleation (site saturation) + (**interface-controlled**) Growth

FORMATION OF BAINITE FERRITE

Nucleation (site saturation) + (**diffusion-controlled**) Growth

$$f = 1 - \exp\left(- N^{*} g \left(\frac{v_0}{\Phi} \right)^{d/m} \left(\exp\left(- \frac{Q}{RT(t)} \right) \frac{RT(t)^2}{Q} \left(1 - \exp\left(\frac{Q\ (T_0 - T(t))}{RT(t)^2} \right) \right) \right)^{d/m} \right)$$



Comparison of experimental and calculated product fraction

Q_{AF}, kJ/mol	124.1
Q_{BF}, kJ/mol	**78.8**

It demonstrates that an initial interface-controlled stage, by the formation of AF and an final diffusion-controlled stage, by the formation of BF.

1100℃/min

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Conclusions

✈ The amount of NbC precipitates increased while the amount of solute Nb went downwards with the isothermal duration increasing at 850℃.

✈ Increasing the amount of NbC precipitates promotes the formation of AF by increasing the nucleation sites, while increasing the solute Nb promotes the formation of BF due to the solute dragging effect of Nb.

✈ A modular approach, incorporating of nucleation, growth and impingement correction, was proven to be a successful tool to describe the kinetic process of the phase transformations.


Thanks

天津大學

HISTORY:

Founded in Oct 2, 1895 as Peiyang University, Tianjin University (TU) is the first university in China.

MOTTO:

Seeking Truth from Facts

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- School of Architecture
- School of Mechanical Engineering
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