Study of ferrite growth in Fe-C-Cr alloys by decarburisation

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Introduction:

- Microstructure knowledge allows providing good properties in steel.

- Decarburisation is a very accurate method to measure ferrite growth in low carbon steels.

- Study two systems: Fe-0.57%C (carbon diffusion coefficient)

  Fe-2%Cr-0.5%C (solute drag quantification)

- Plan:
  I. Theory of decarburisation
  II. Experimental procedures and optimisations
  III. Decarburisation of Fe-Cr-C

I. Theory of decarburisation:

- Equation of Decarburisation :

$$C + \frac{1}{2} O_2 \leftrightarrow CO$$

But oxide formation is possible: $$x\,M + \frac{y}{2} O_2 \leftrightarrow M_x O_y$$

Hydrogen bubbling in water allow knowing the oxygen partial pressure:

$$H_2 + \frac{1}{2} O_2 \leftrightarrow H_2O \quad \Longrightarrow \quad P_{O_2} = \frac{P_{H_2O}}{P_{H_2}} e^{\frac{2\Delta G_{H_2O}}{RT}}$$

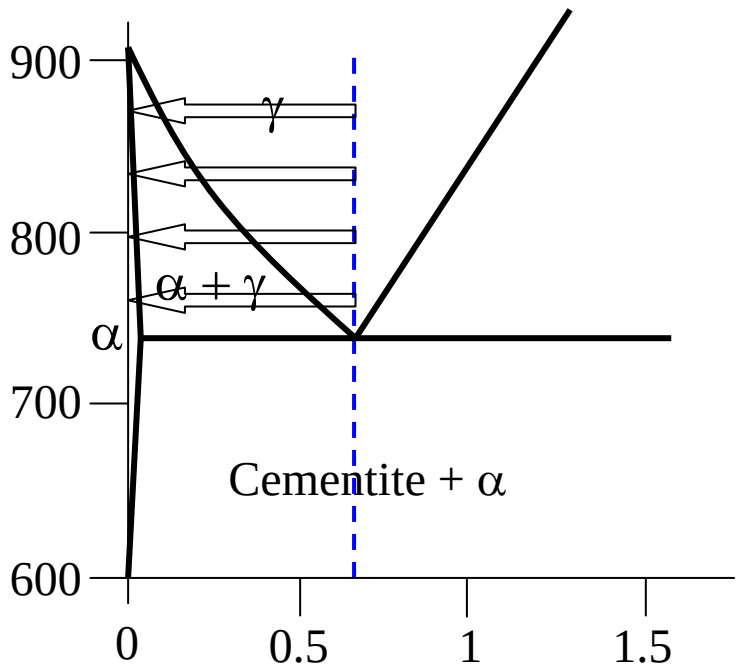
And the existence of eventual oxide:

$$P_{O_2\,\max} = e^{\frac{2}{y}\frac{\Delta G_{M_xO_y}}{RT}}$$

- Alloys composition :

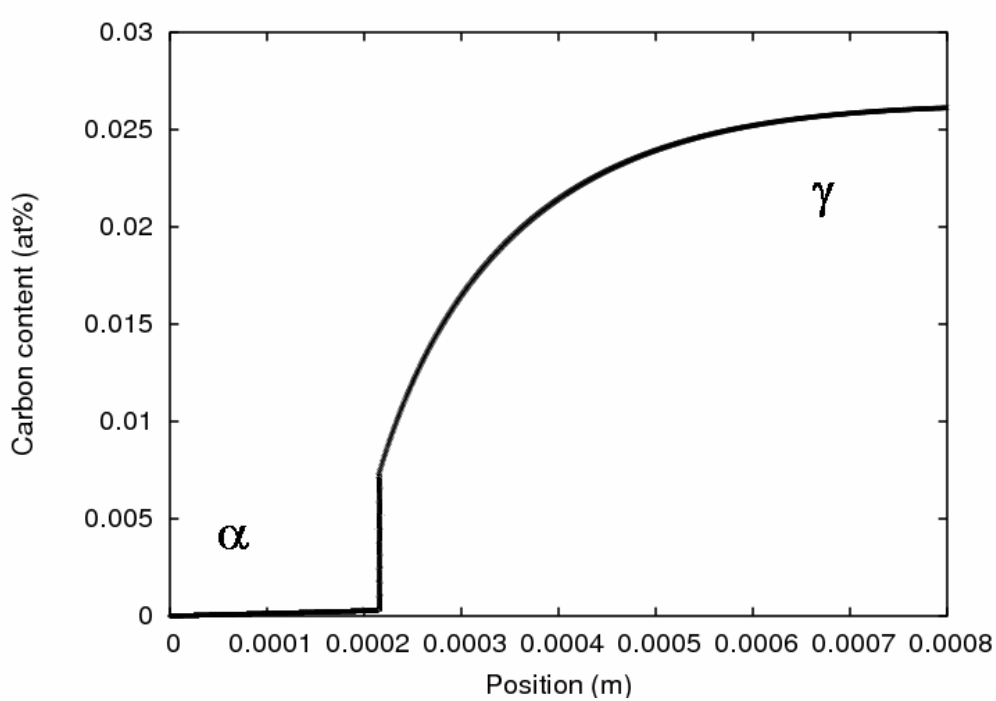
Need of wide range of temperature ⇨ Large zone of coexistence of α and γ

Phase diagram gives the optimal composition in carbon:



- Calculation of the carbon profile:

Decarburisation is only mastered by diffusion law.



To numerically solve the problem, diffusion coefficient in both α and γ and concentration in carbon at the interface have to be know.

- Diffusion coefficients :

Agren and al. found equation to model the carbon diffusion in ferrite and austenite.

In ferrite:

$$D_\alpha = 2.10^{-6} e^{\left(\frac{-10115}{T}\right)} e^{\left(0.58981 + \frac{2}{\pi}\arctan\left(14.985 - \frac{15309}{T}\right)\right)}$$

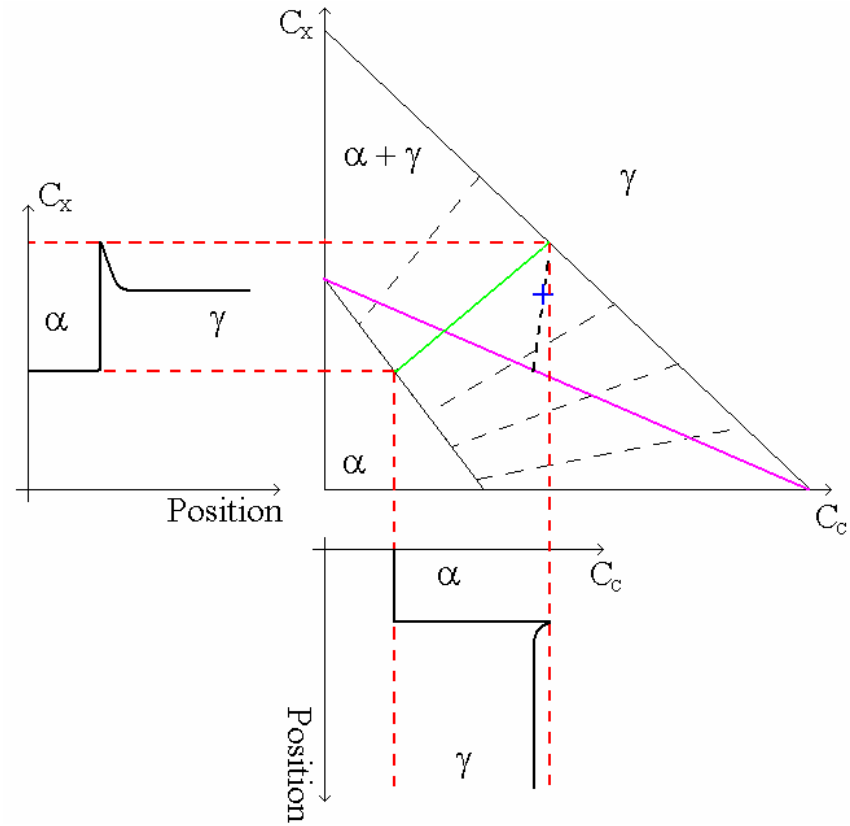
In austenite:

$$D_\gamma = 4.53.10^{-7}\left(1 + \frac{X_{c\gamma}}{1 - X_{c\gamma}}\frac{8339.9}{T}\left(1 - \frac{X_{c\gamma}}{1 - X_{c\gamma}}\right)\right) e^{-\left(\frac{1}{T} - 2.221.10^{-4}\right)\left(17767 - 26436\frac{X_{c\gamma}}{1 - X_{c\gamma}}\right)}$$

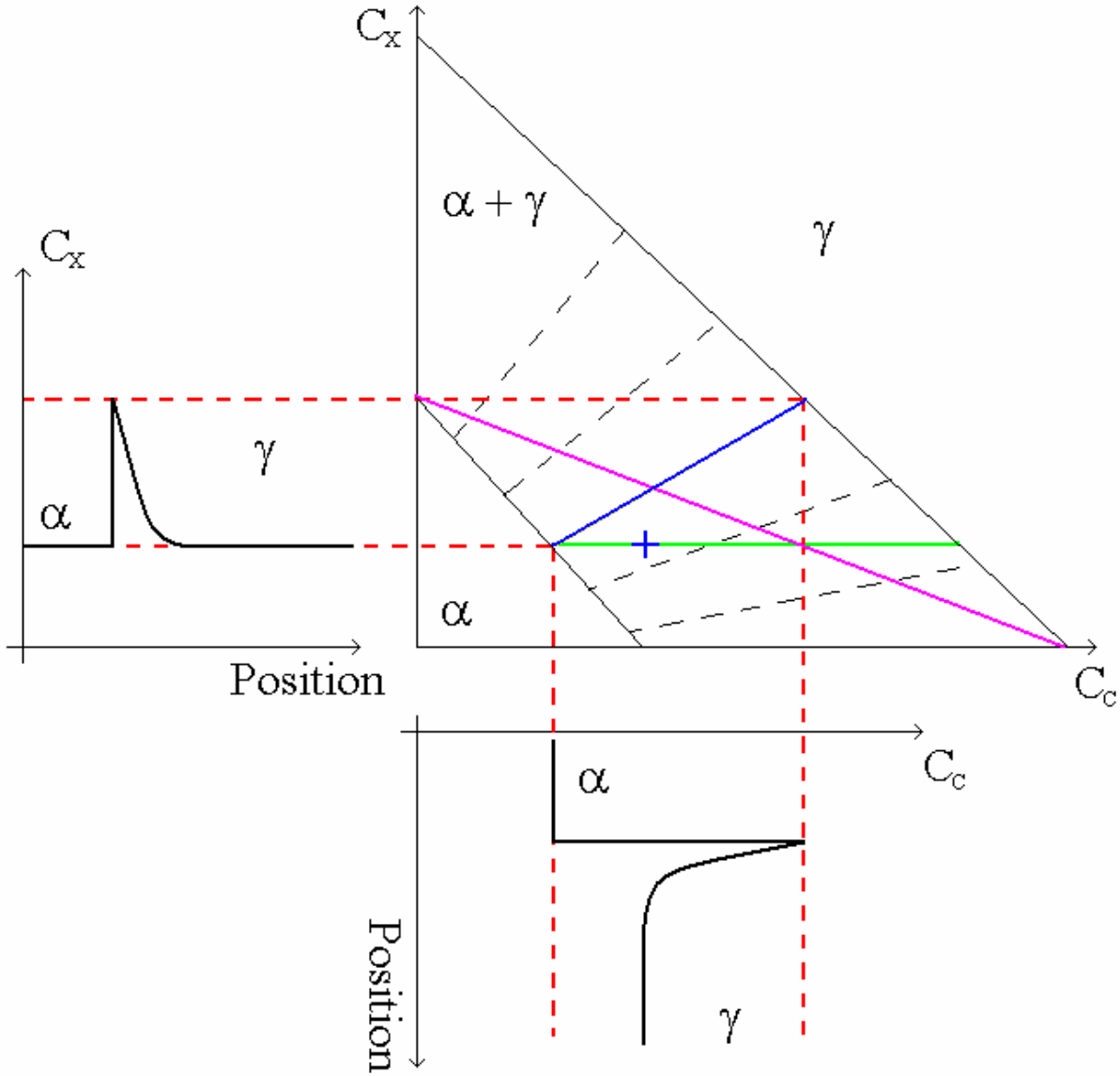
- Concentration of carbon at the interface:

Three different predictive models exist depending the interface velocity: LEP, LENP and PE.

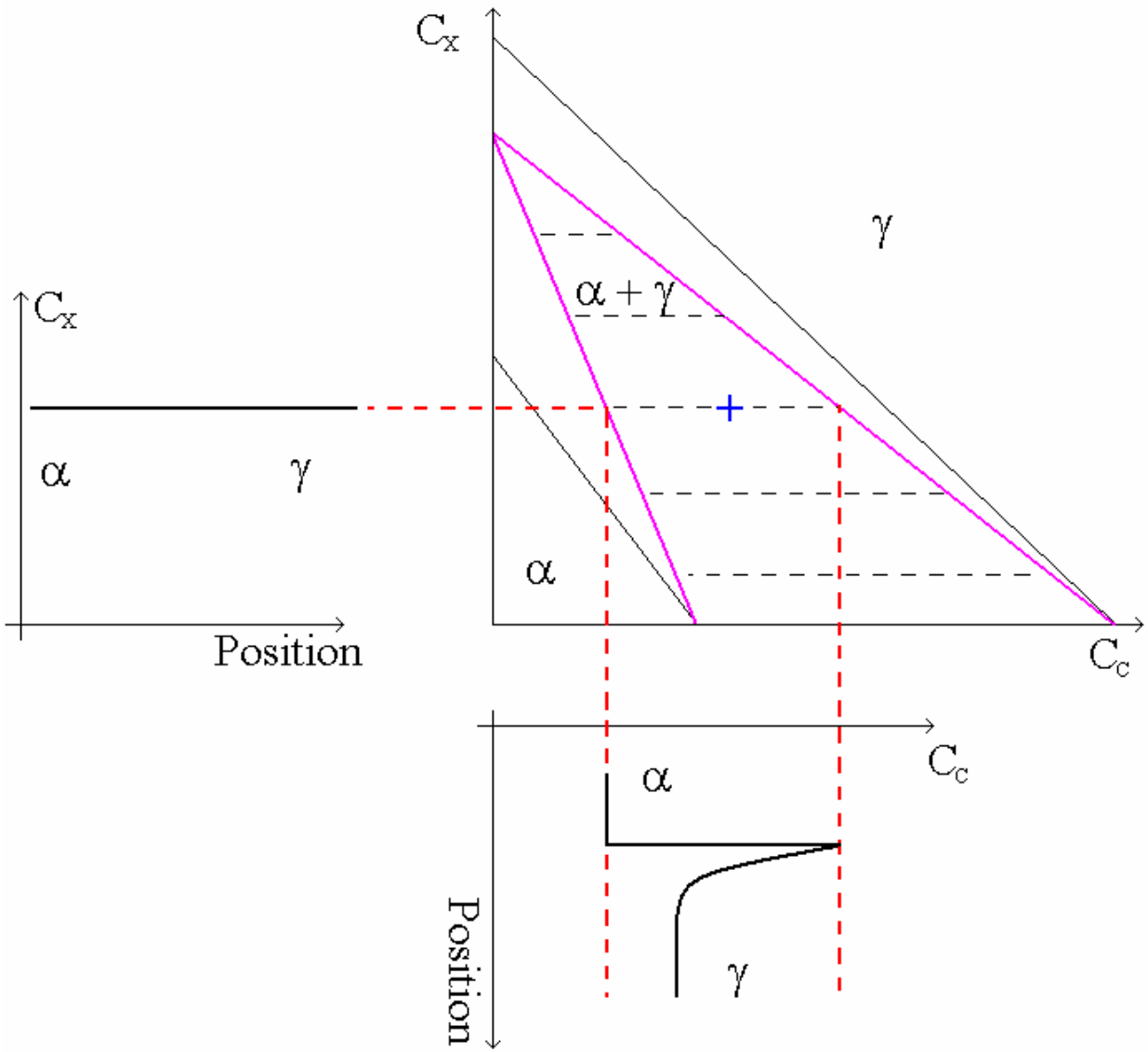
LEP (Local equilibrium partitioning):



LENP:


C_x
$\alpha + \gamma$
γ
C_x
γ
α
α
Position
C_c
C_c
α
Position
γ

PE:


C_x
γ
$\alpha + \gamma$
C_x
α
γ
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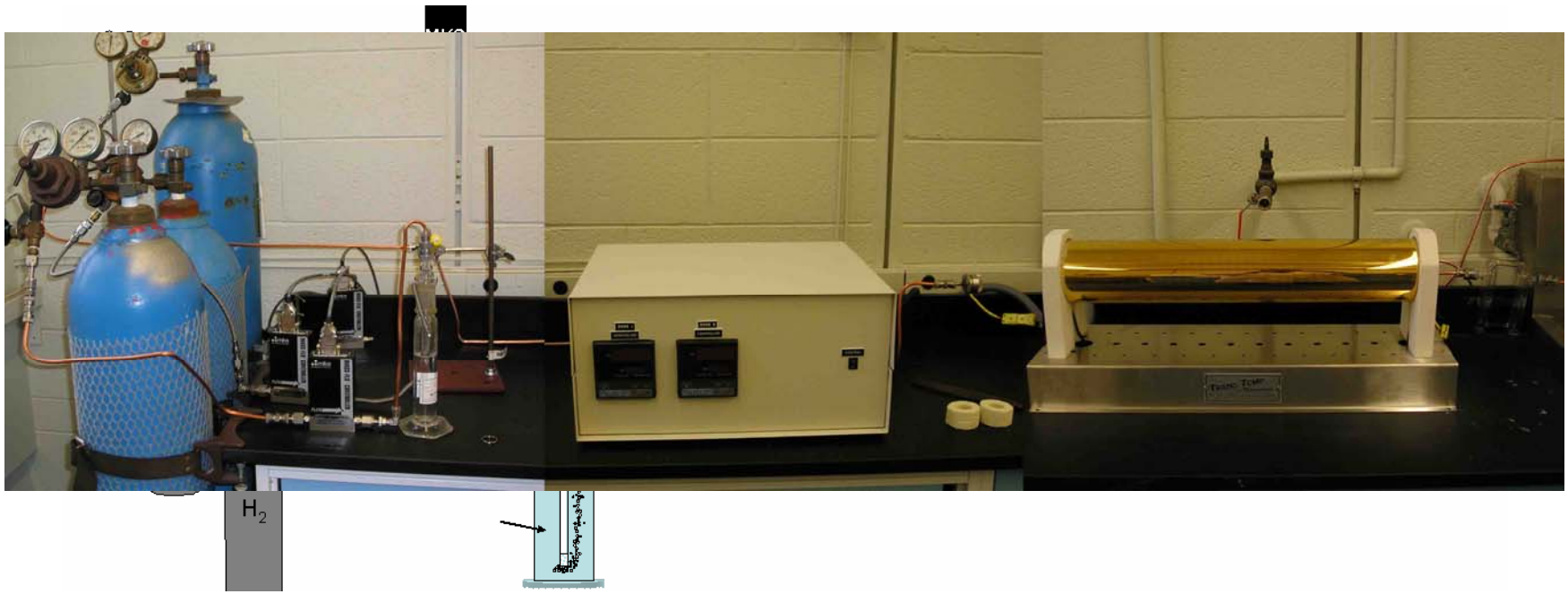
Position
C_c
C_c
α
γ
Position

II. Experimental procedures and optimisations:

- Furnace organisation:



- Optimisations:

Iron plating by electrodeposition for samples presenting oxide formation. Average thickness is taken around 5 μm to not disturb carbon diffusion.

Water temperature and hydrogen flux have been optimized using Fe-2%Cr-C samples:

	Furnace temperature	Time	Water temperature	Wet H_2 ($cm^3.min^{-1}$)	Dry H_2 ($cm^3.min^{-1}$)	Layer thickness (μm)	Standard deviation (μm)
1	806ºC	64 min	R-T	50	250	---	---
2	806ºC	64 min	0ºC	50	---	148,95	3,27
3	806ºC	64 min	R-T	50	---	159,59	0,67
4	806ºC	64 min	R-T	17	---	143,86	0,81

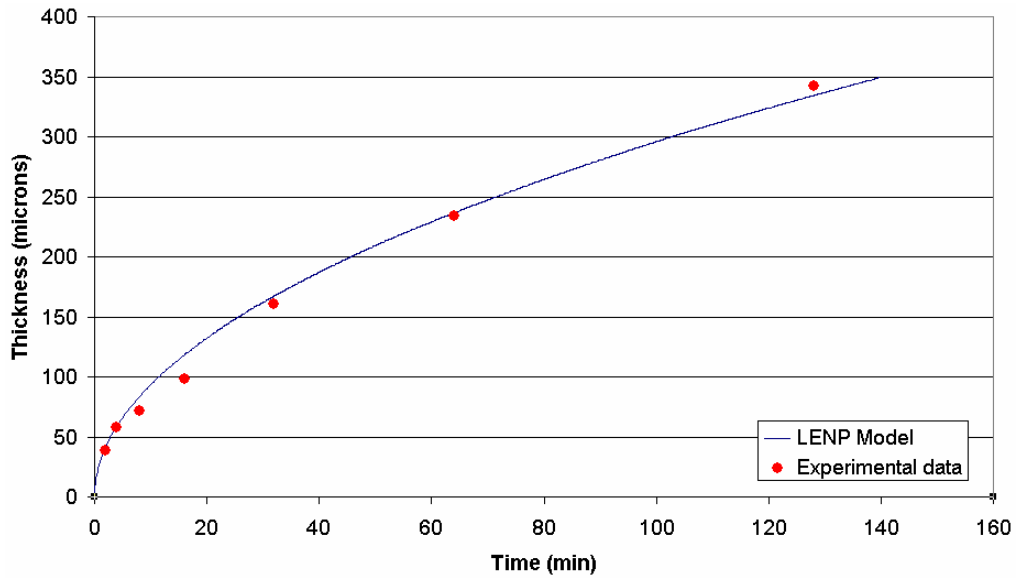
- Diffusion coefficient correction using Fe-0.56%C alloy:

Magnetic transition appears in the range of temperature studied.

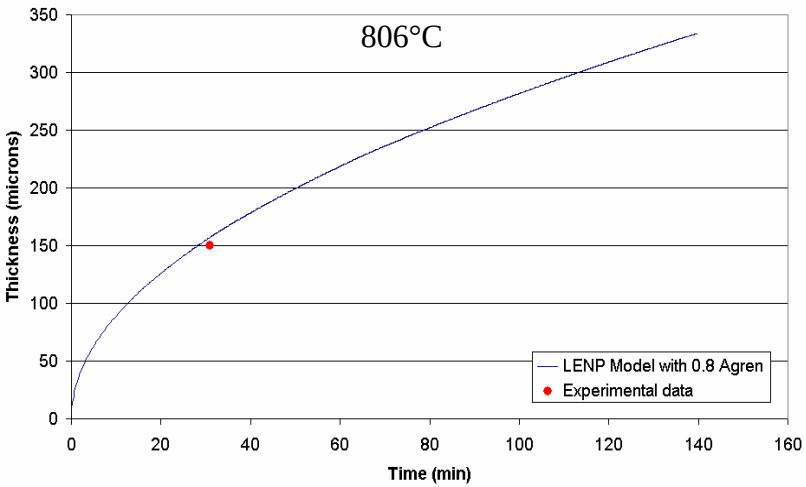
Experiments required to correct Agren's data in that zone.

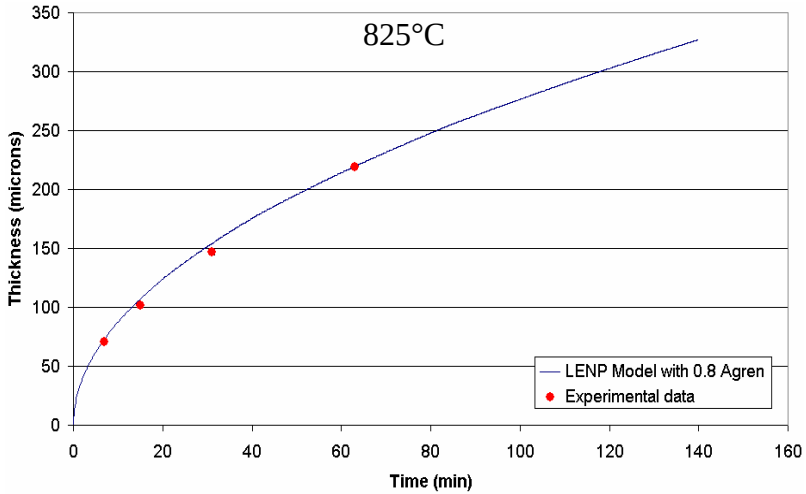
Fe-C follow exactly the LENP model.

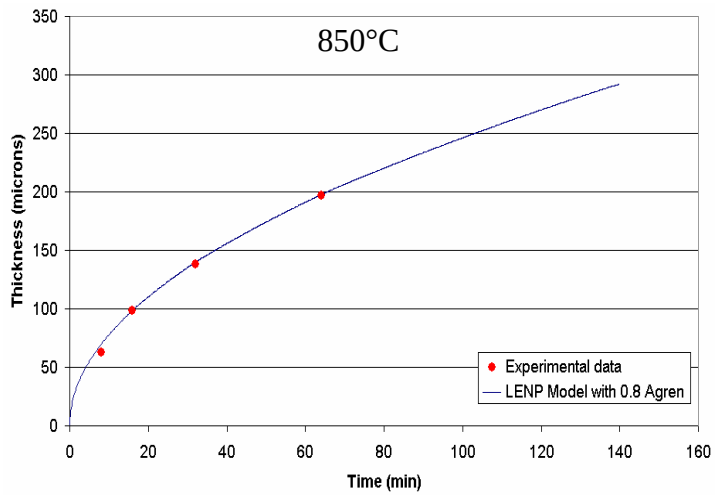
At 775°C, no correction needed



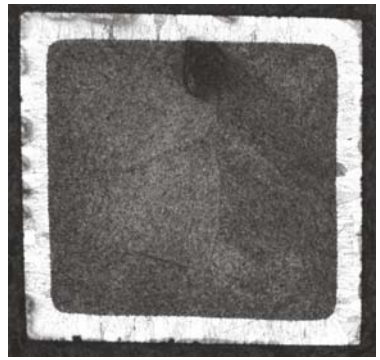
For the temperature above 806°C, a multiplicative factor of 0.8 is needed to perfectly match the data.







III. Decarburisation of Fe-Cr-C:



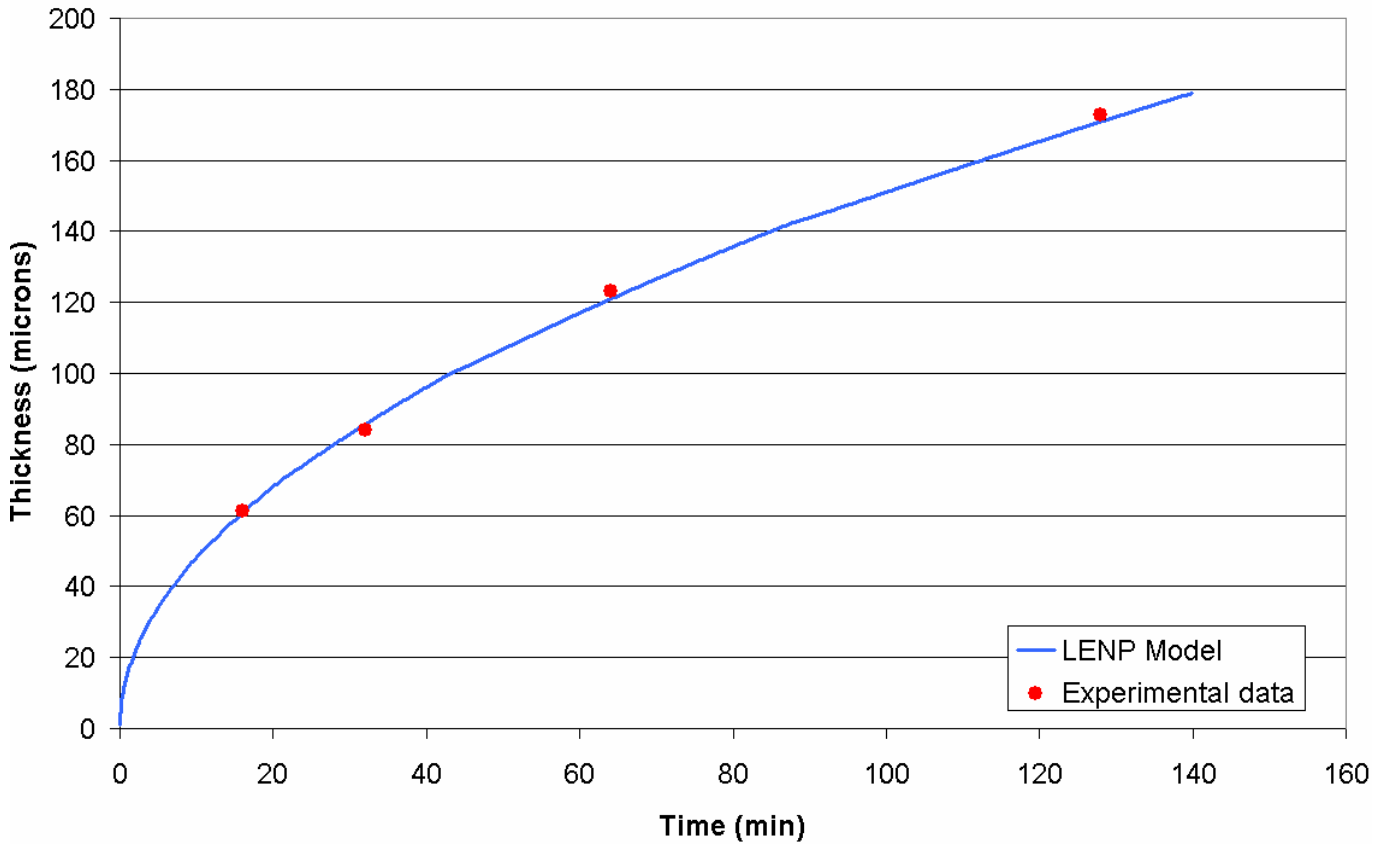
- Composition chosen at 2 wt% Cr and 0.57 wt% C.
- For T=850°C:

Very good accuracy

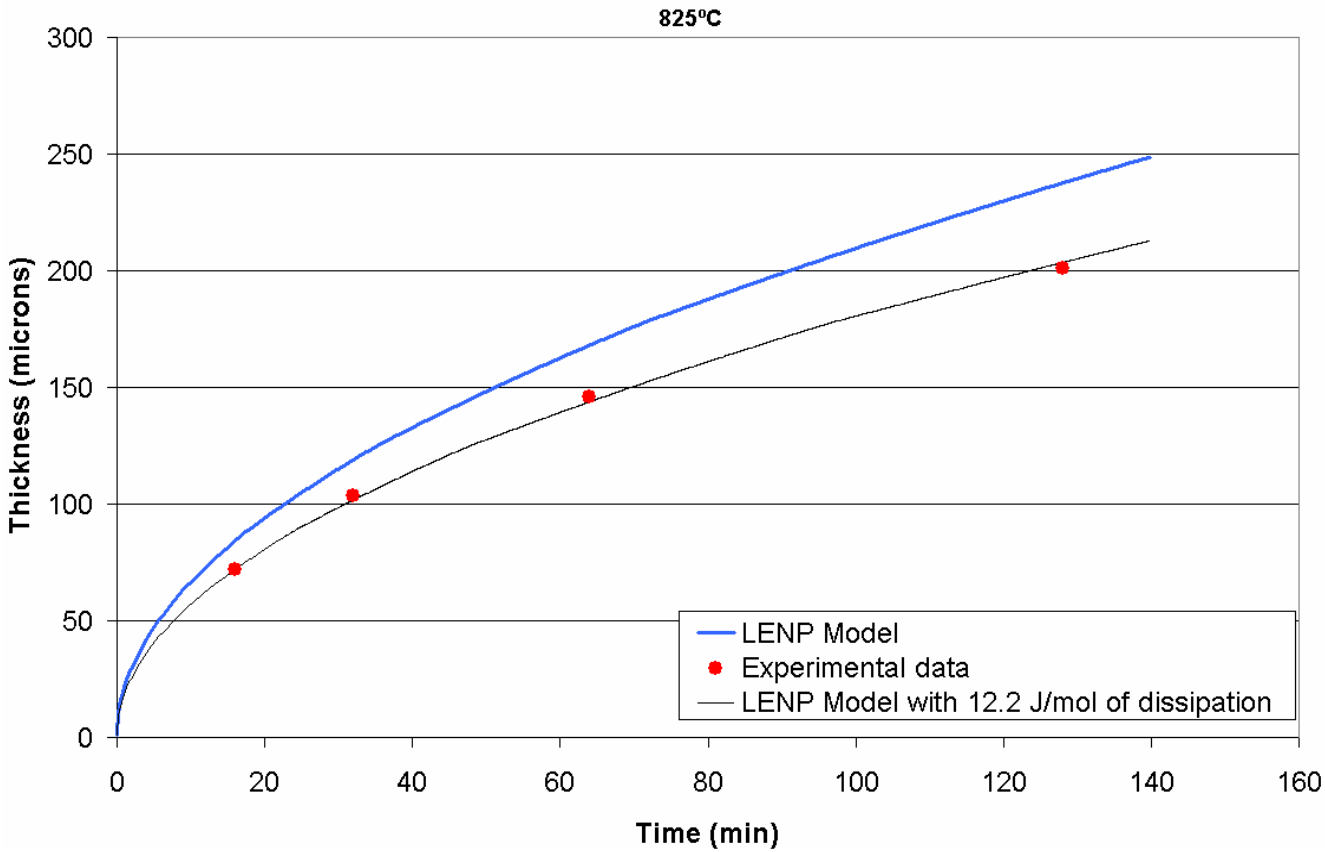
No dissipation

⇩

No oxide formation

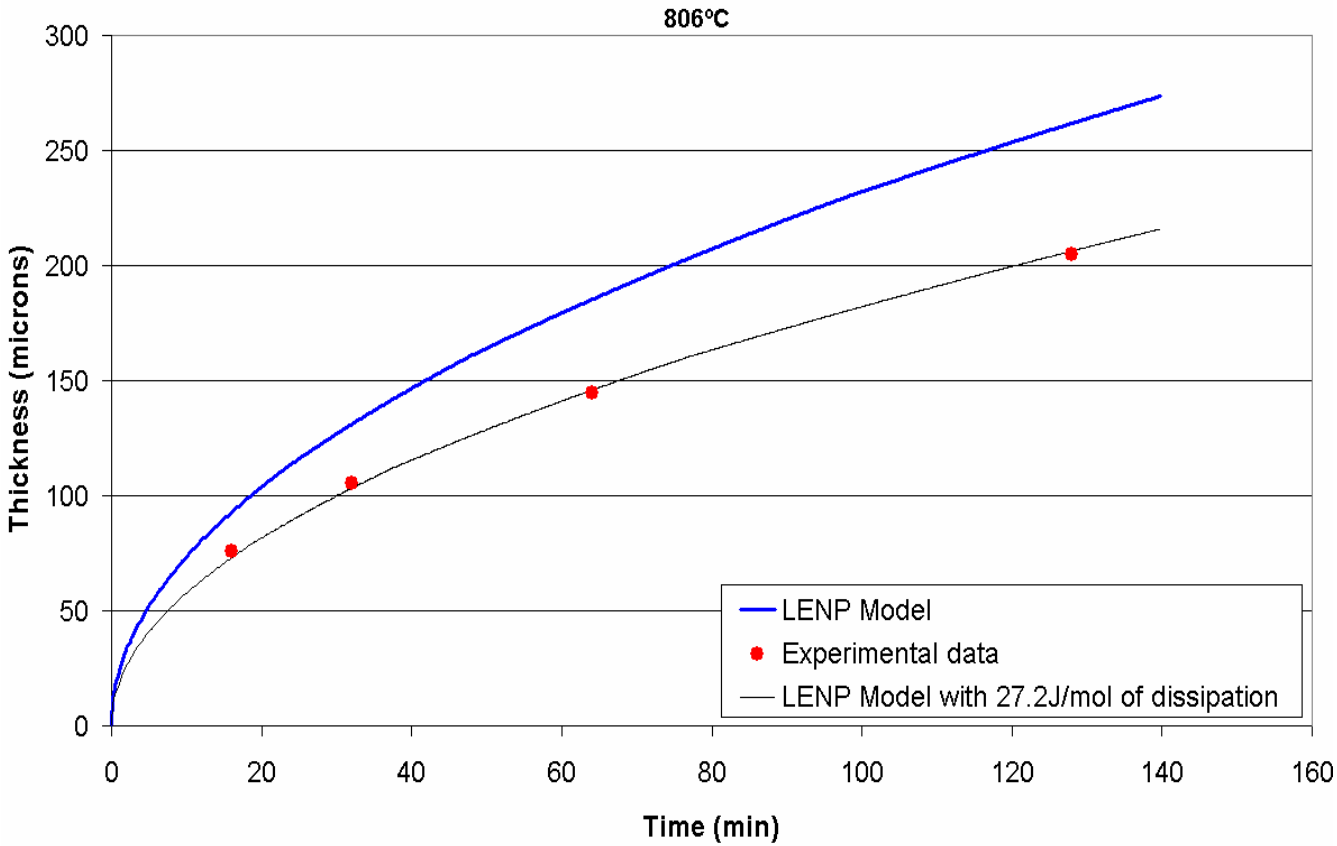


- For T=825°C:



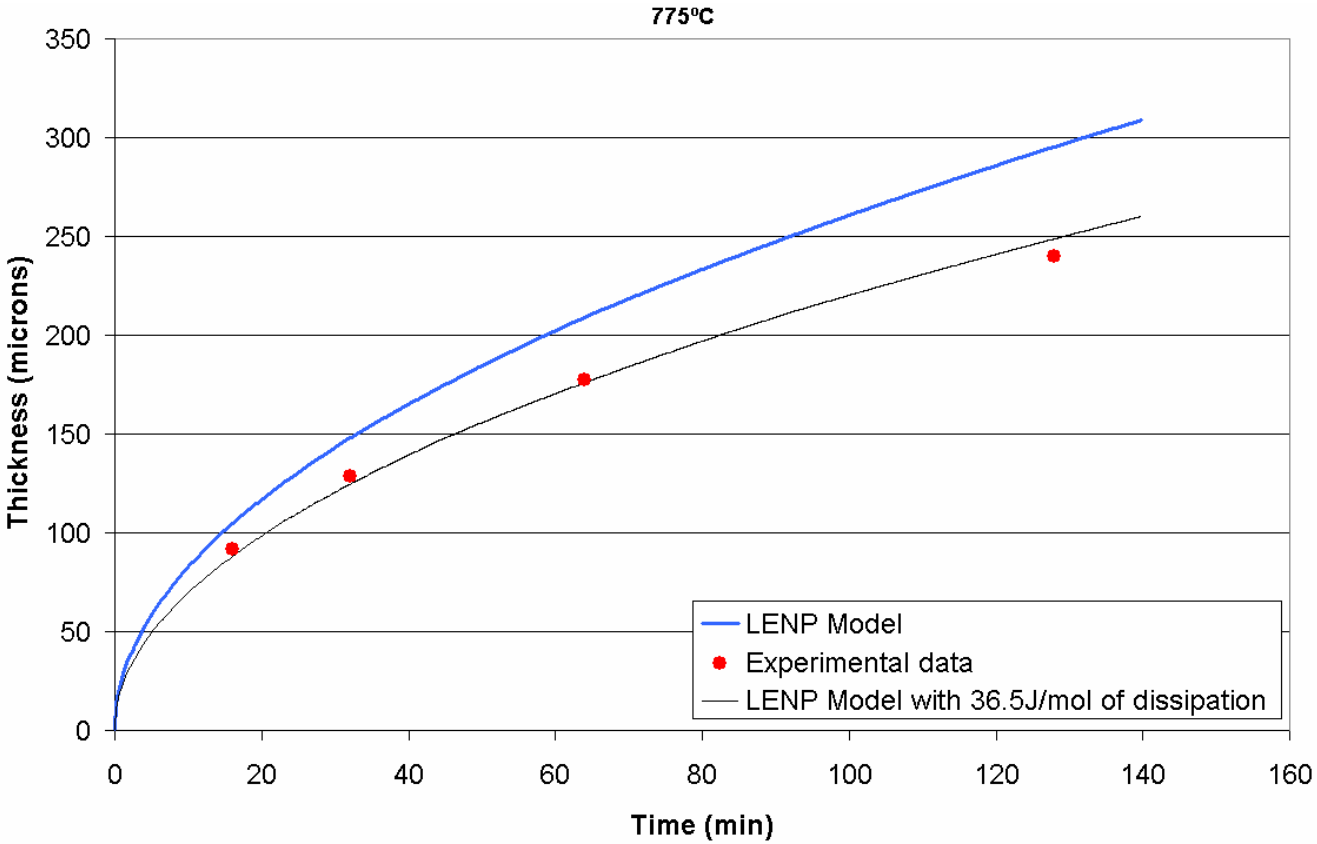
12.2 J/mol of dissipation

- For T=806°C:



27.2 J/mol of dissipation

- For T=775°C:

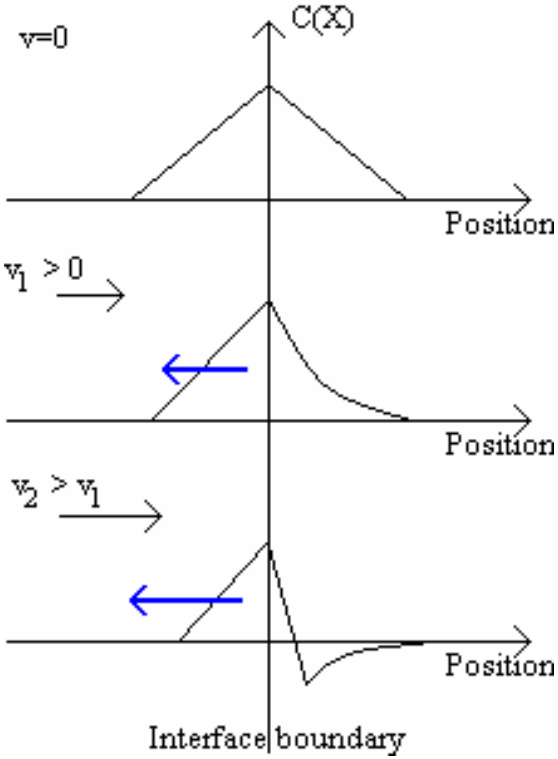


36.5 J/mol of dissipation

Augmentation of the dissipation with the temperature decrease.

- Solute drag model:

Solute drag slow down the boundary motion:



Modeling proposed by Cahn et al.:

$$P_{SD} = 1.10^{-9} \frac{(kT)^2}{D_{Cr} E_0} \left(\sinh \frac{E_0}{kT} - \frac{E_0}{kT} \right) C \nu \qquad \text{with} \qquad D_{Cr} = ae^{\left(\frac{-Q}{RT} \right)}$$

- Identification to solute drag model:

850°C result can not be use.

Three dissipations for three unknowns: E_0, Q and a.

$$P_{SD} = 1.10^{-9} \frac{(kT)^2}{D_{Cr} E_0} \left(\sinh \frac{E_0}{kT} - \frac{E_0}{kT} \right) C \nu \qquad \text{with} \qquad D_{Cr} = a e^{\left(\frac{-Q}{RT} \right)}$$

Magnetic transition in the range of temperature hampers the solution obtainment.

From literature, E_0 = 15 kJ ⟹ D_{Cr} can be approximate

	D_{Cr} experimental (10^{-18} $m^2.s^{-1}$)	D_{Cr} in ferrite (10^{-18} $m^2.s^{-1}$)	D_{Cr} in austenite (10^{-18} $m^2.s^{-1}$)
775ºC	11.7	220 to 2500	0.88 to 3.1
806ºC	13.7	470 to 5800	2.2 to 8.0
825ºC	32.5	750 to 9400	0.14 to 3.8

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Conclusion:

- Verification of carbon diffusion coefficient in austenite

  Correction needed above the magnetic transition temperature

- Decarburisation of Fe-Cr-C alloy

  Presence of solute drag effect

  Not enough data to get the solute drag force

- Measurement of the chromium diffusion coefficient across the α–γ boundary.

  Value comprises in between chromium diffusion coefficient in α and γ

- Future work: more decarburisation temperatures ?