Kinetic Transitions in Fe-Mn-C Alloys

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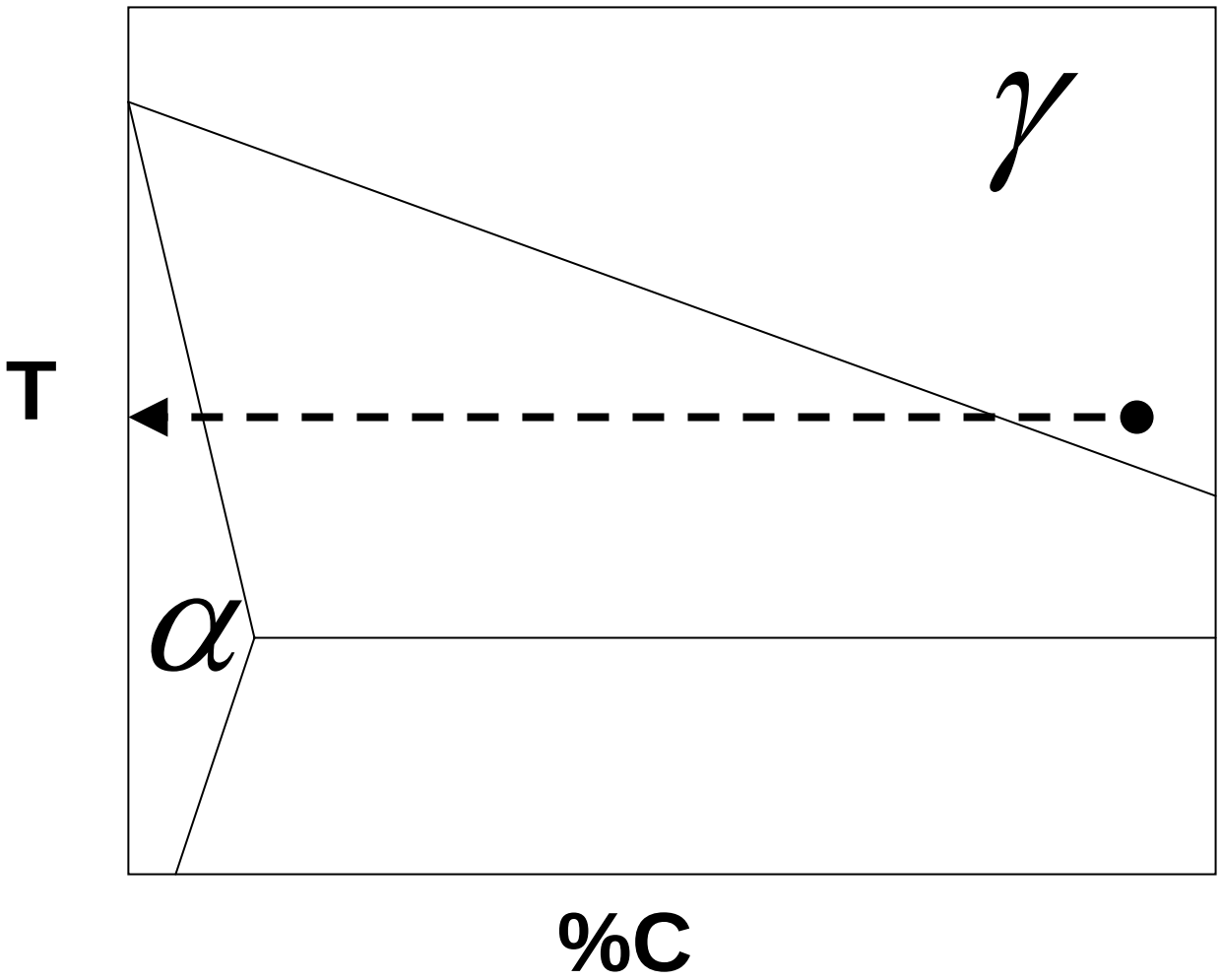
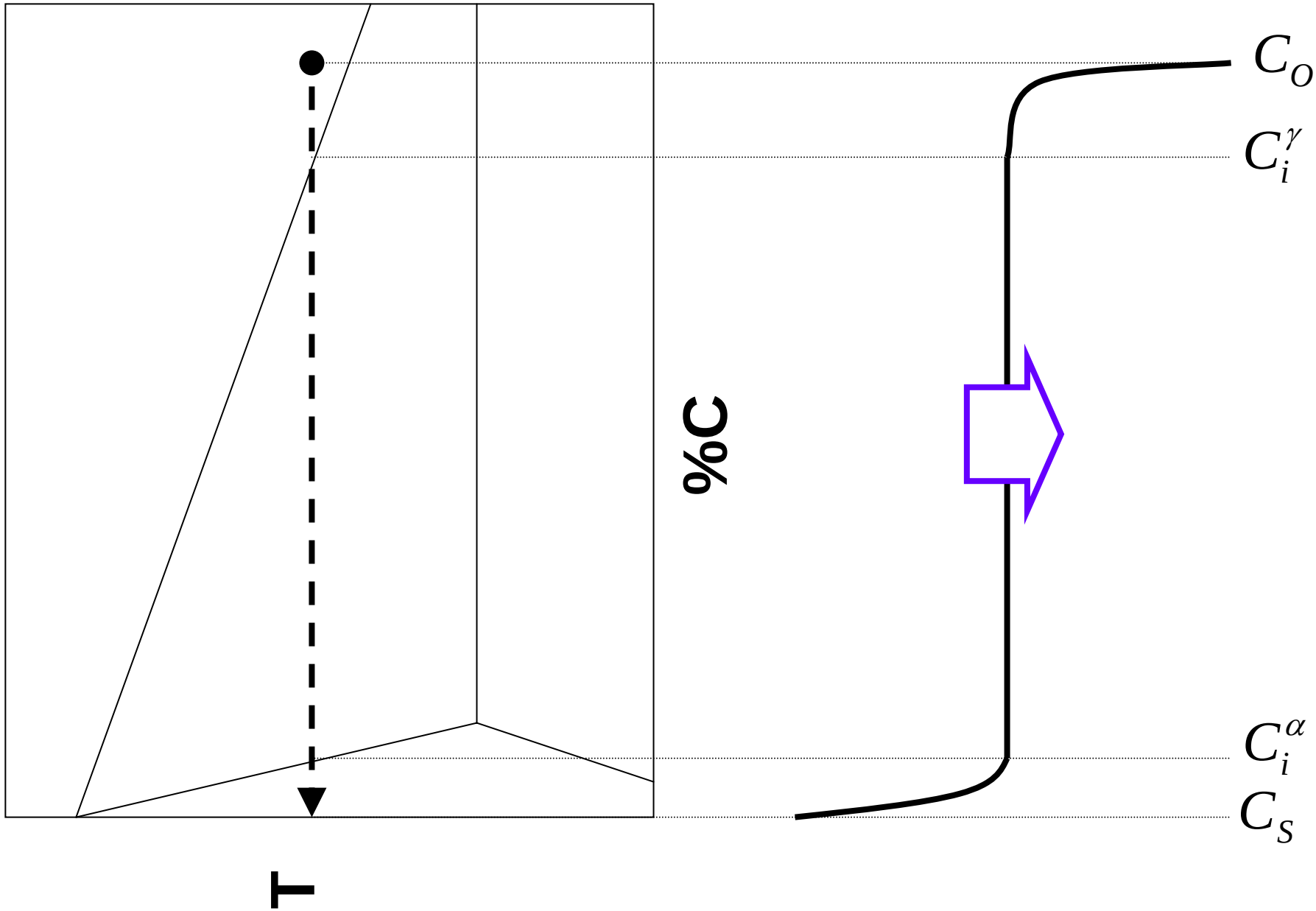
Outline

- Decarburization as a method of studying the $\gamma \rightarrow \alpha$ transformation.
- Summary of results on Fe-Ni-C.
- New results on Fe-Mn-C
  - Fe-1%Mn
  - Fe-0.5%Mn
  - Fe-2%Mn
- Possible Interpretations
- Conclusions

The Decarburization Approach:

> *Background:*




C_o
C_i^{γ}
%C
C_i^{α}
C_S
T

The rate of interface motion is given by:

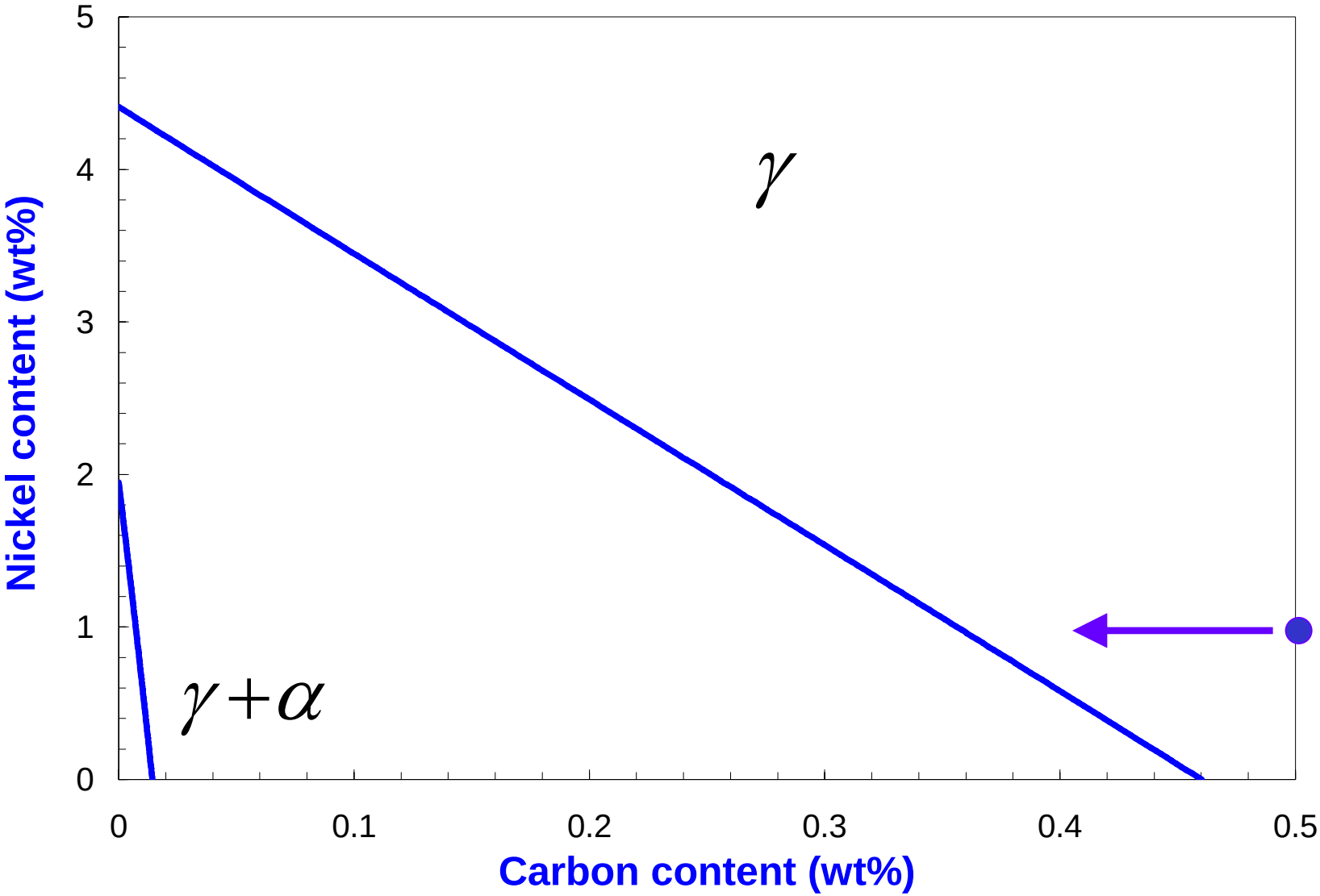
$$\frac{dz}{dt} = \frac{J_i^{\alpha} - J_i^{\gamma}}{C_i^{\gamma} - C_i^{\alpha}}$$

This differential equation has an analytical solution of the form:

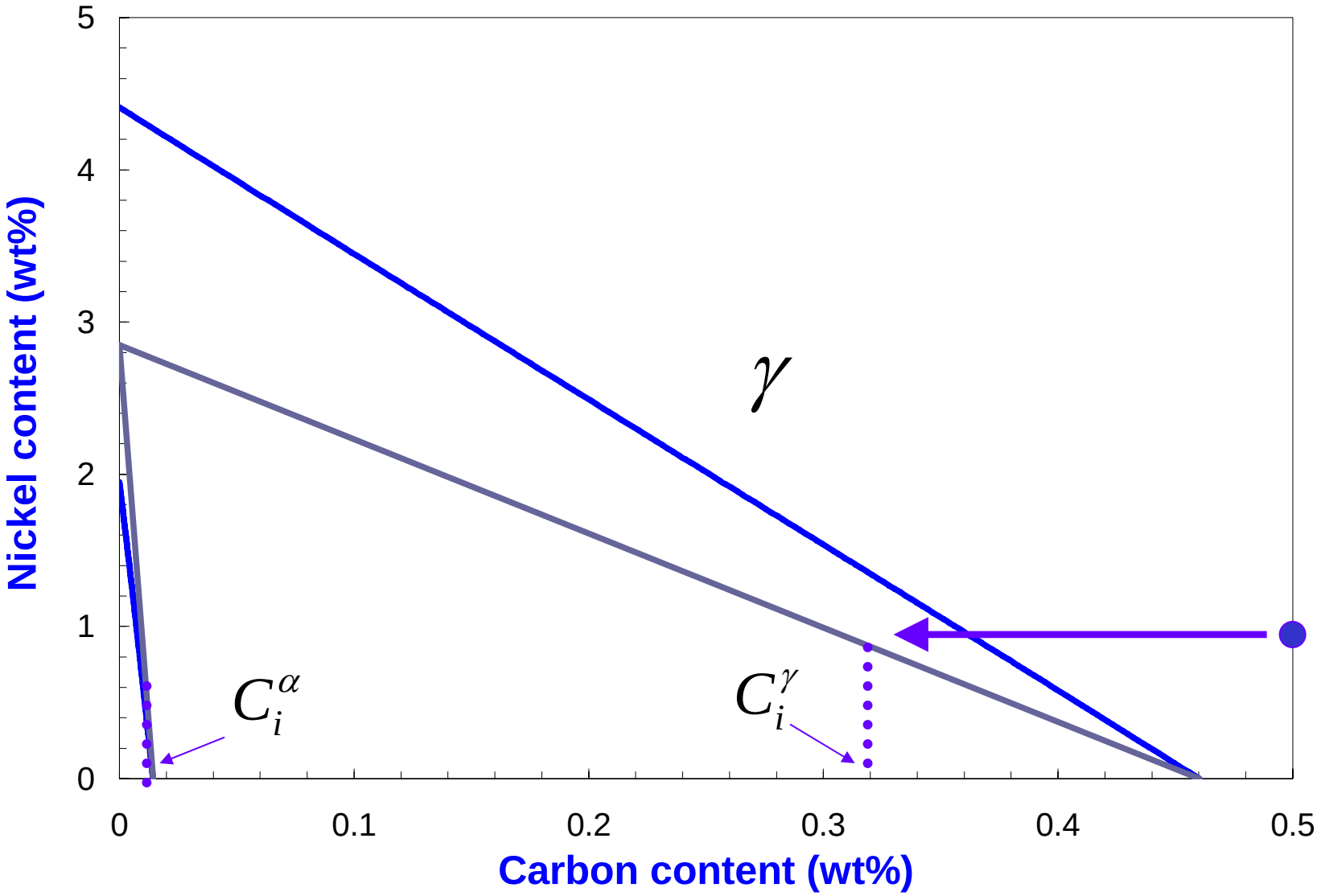
$$z = B\sqrt{t}$$

$$B = f(C_i^{\alpha}, C_i^{\gamma}, C_O)$$

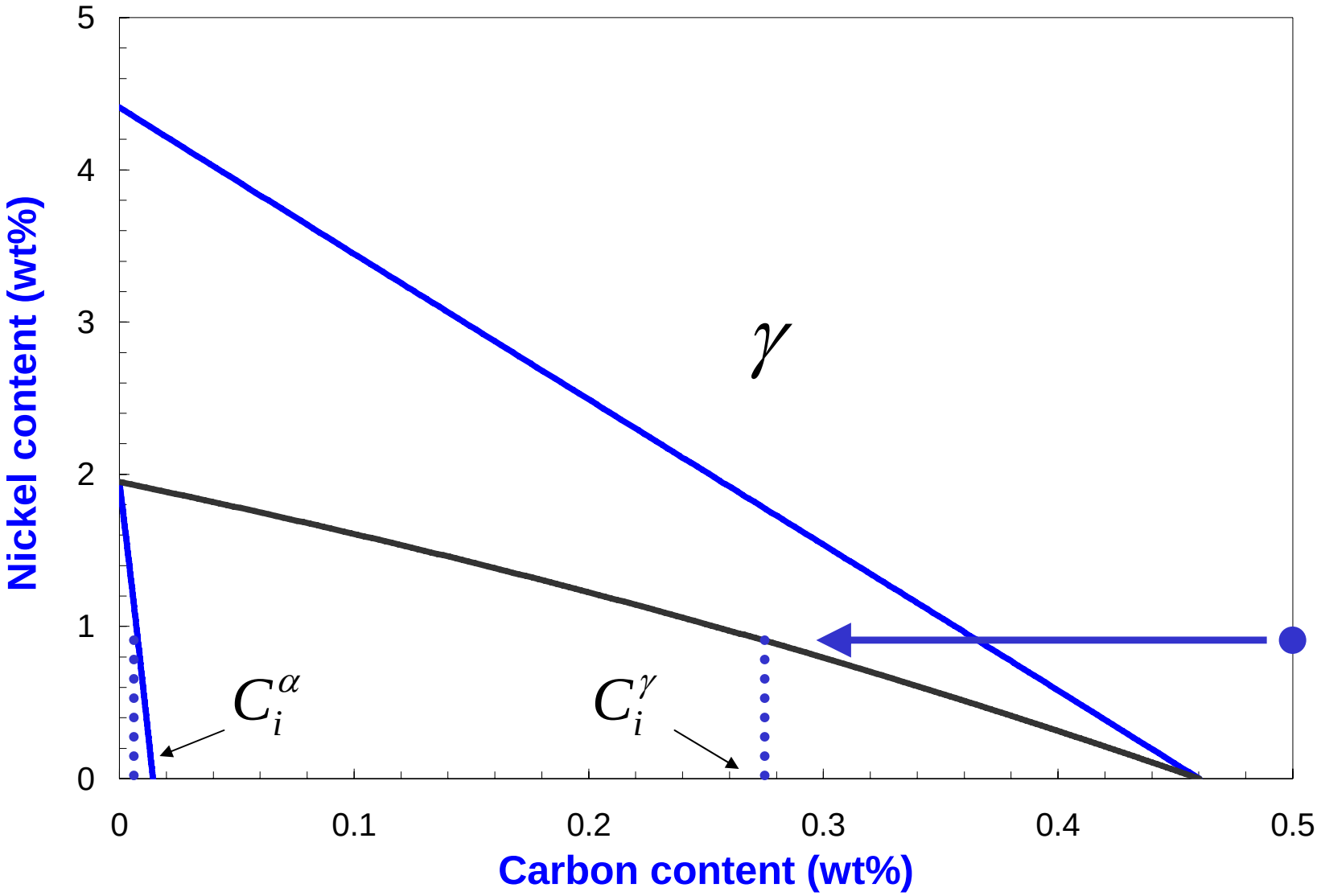
> *Ternary Alloys.*

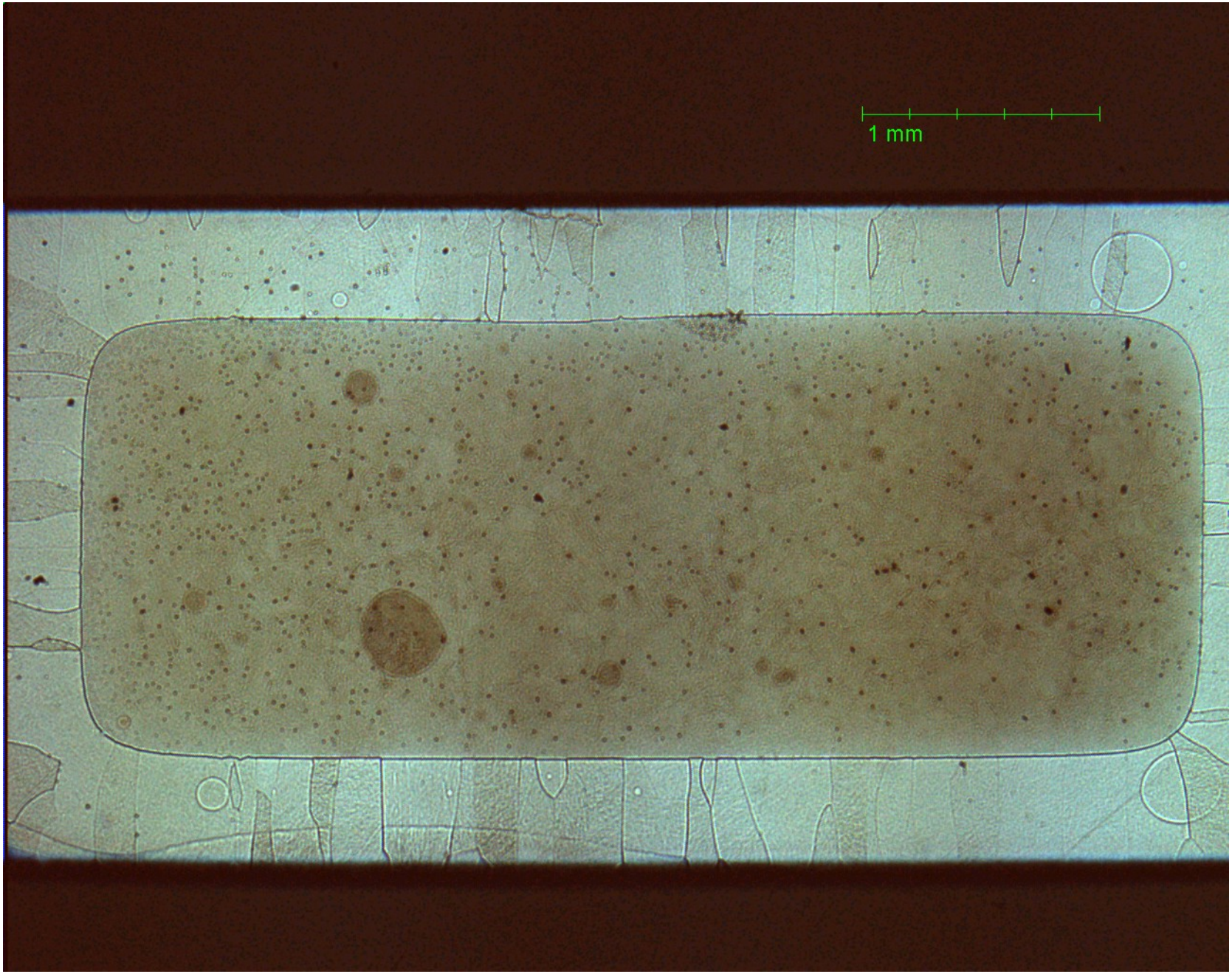


> *Ternary Alloys: ParaEquilibrium Limit.*



> *Ternary Alloys: NPLE Limit.*



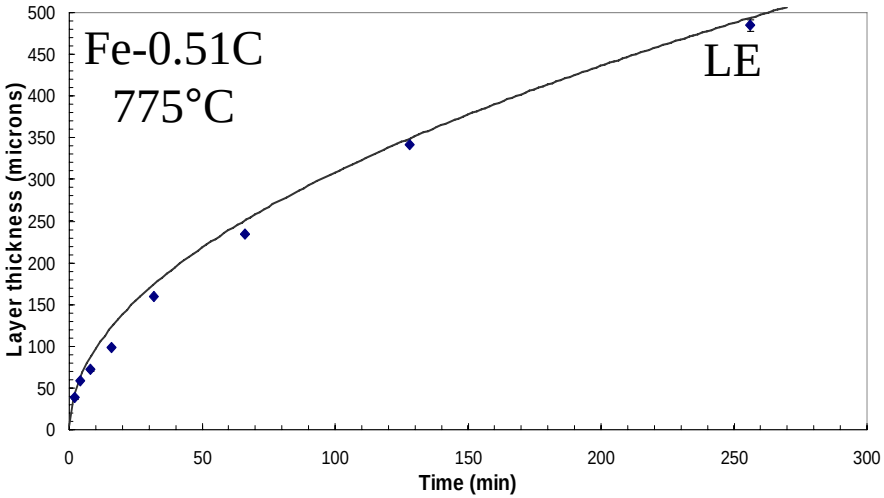

1 mm

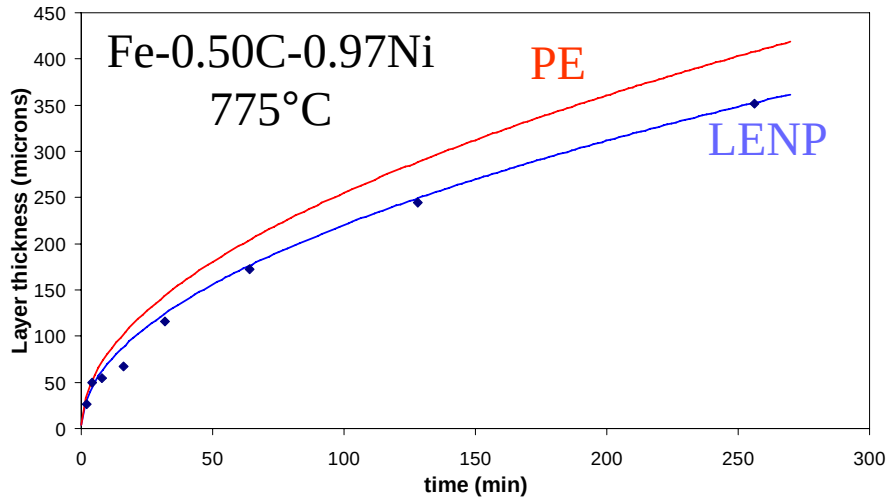
Summary of Results on Fe-Ni-C

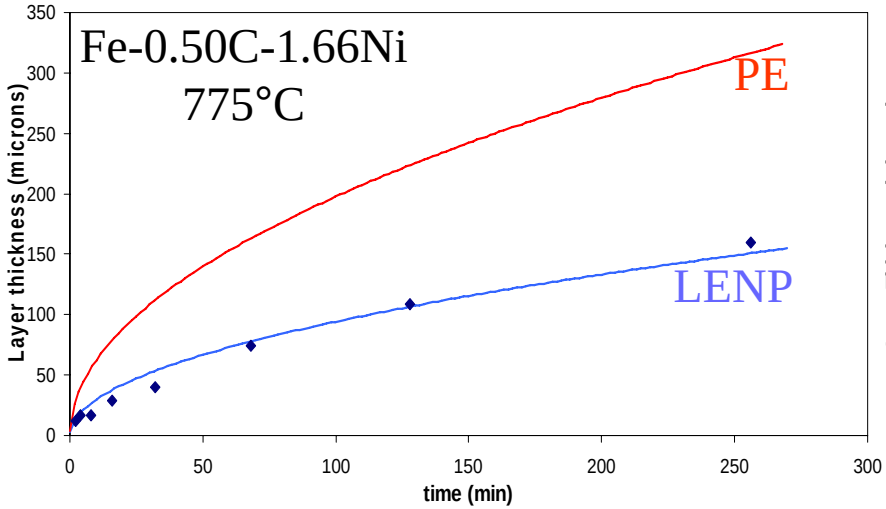
- Fe-Ni-C alloys seems to follow LE-NP kinetics at all the temperatures and compositions investigated

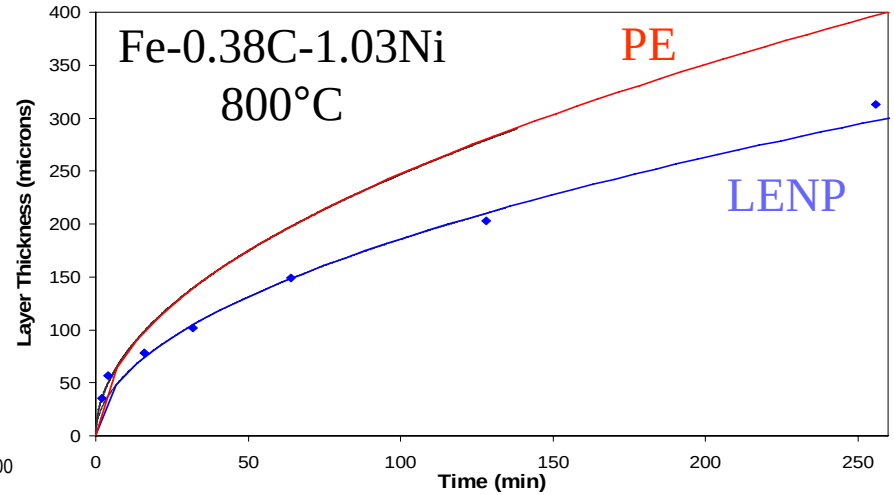
Fe-C-Ni: decarburization kinetics

Phillion, Zurob, Hutchinson, Guo, Malakhov, Nakano and Purdy, *Metall Trans*., 35A, 1237-1242, 2004.



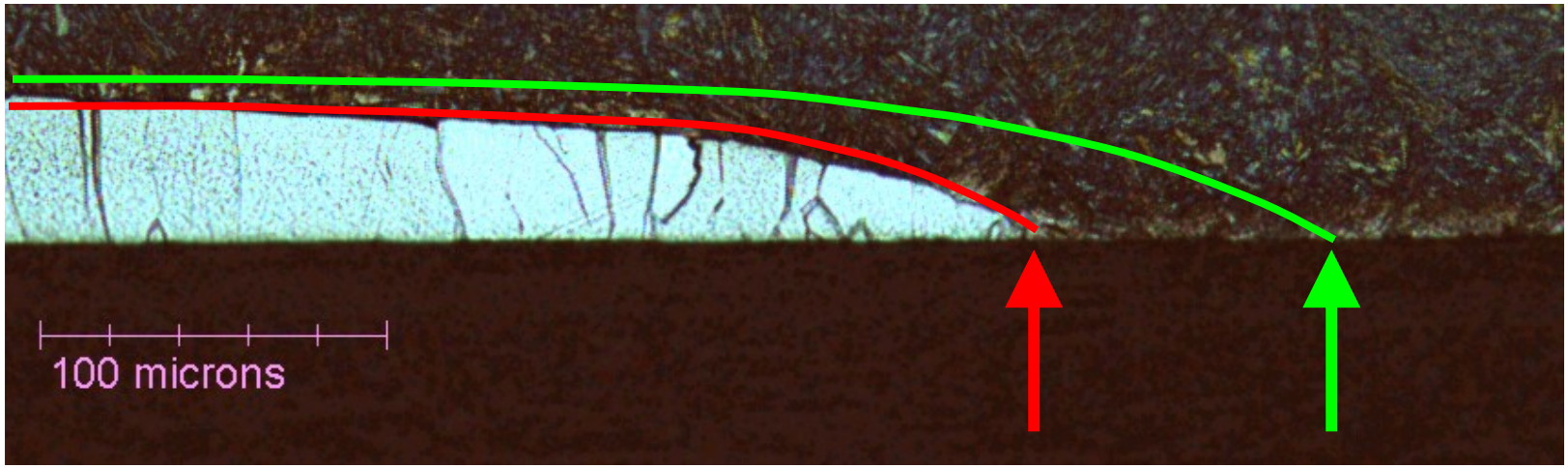






Fe-C-Ni: diffusion couples

Phillion, Zurob, Hutchinson, Guo, Malakhov, Nakano and Purdy, *Metall Trans*., 35A, 1237-1242, 2004.



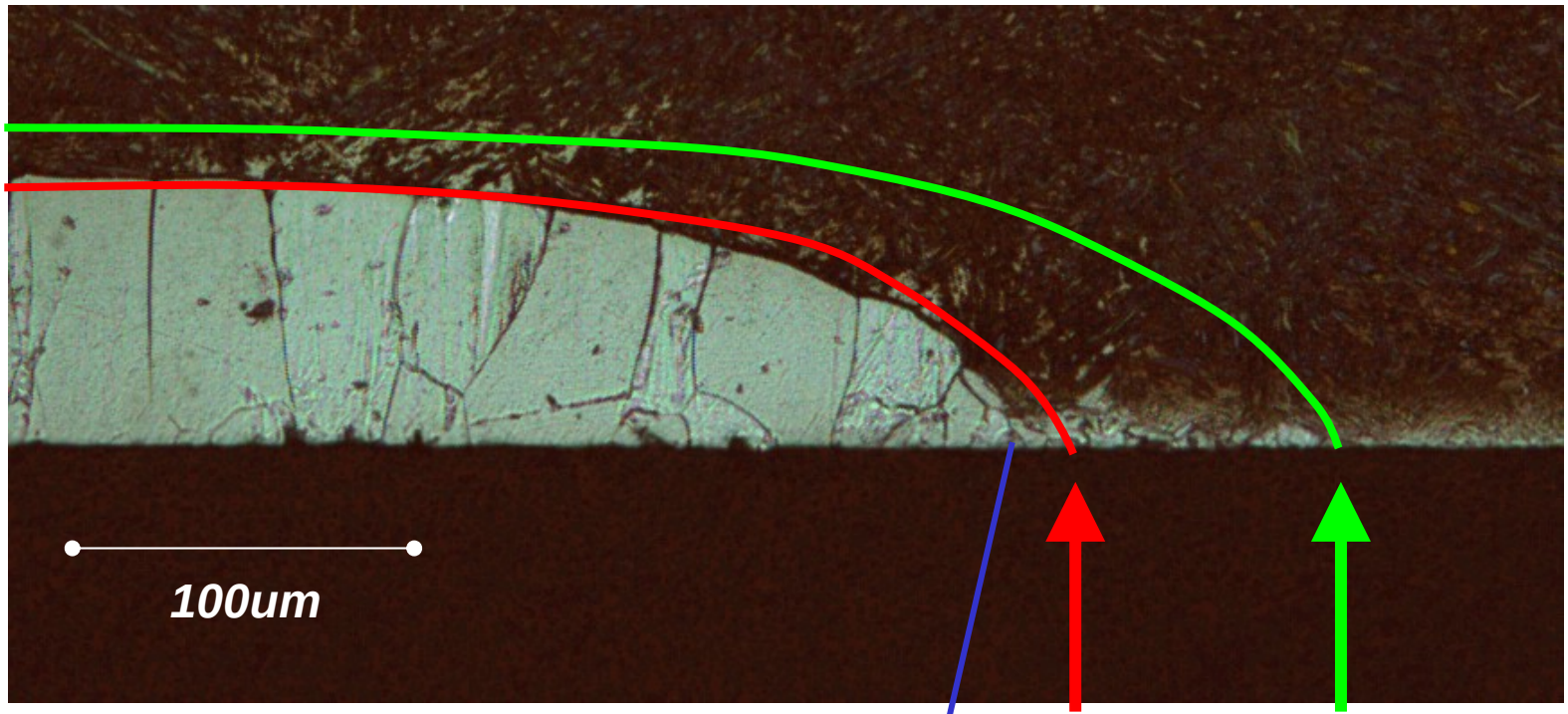
775°C for 4 min.

1.95% **2.85%**

1.89 +/- 0.33

Fe-C-Ni: diffusion couples

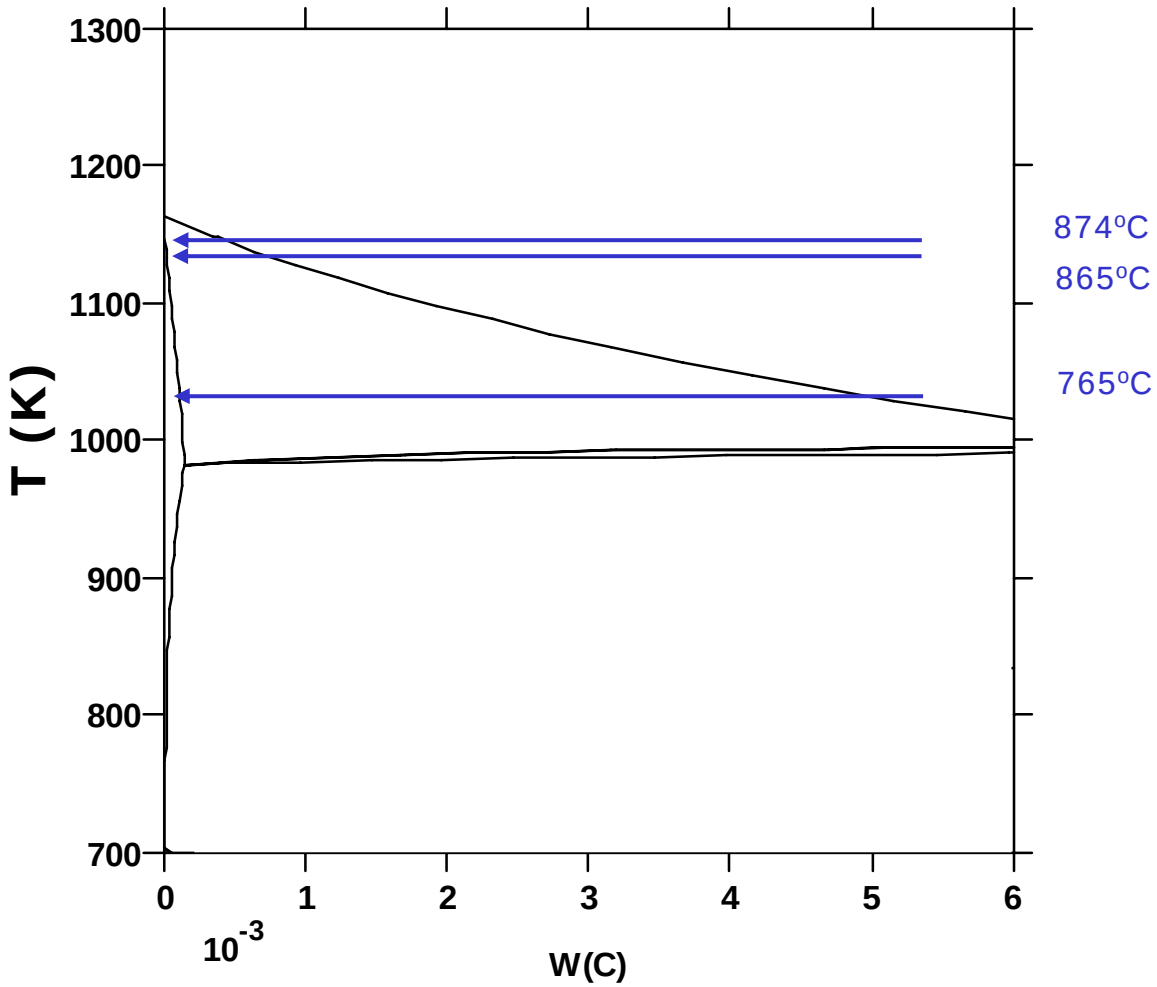
Phillion, Zurob, Hutchinson, Guo, Malakhov, Nakano and Purdy, *Metall Trans*., 35A, 1237-1242, 2004.



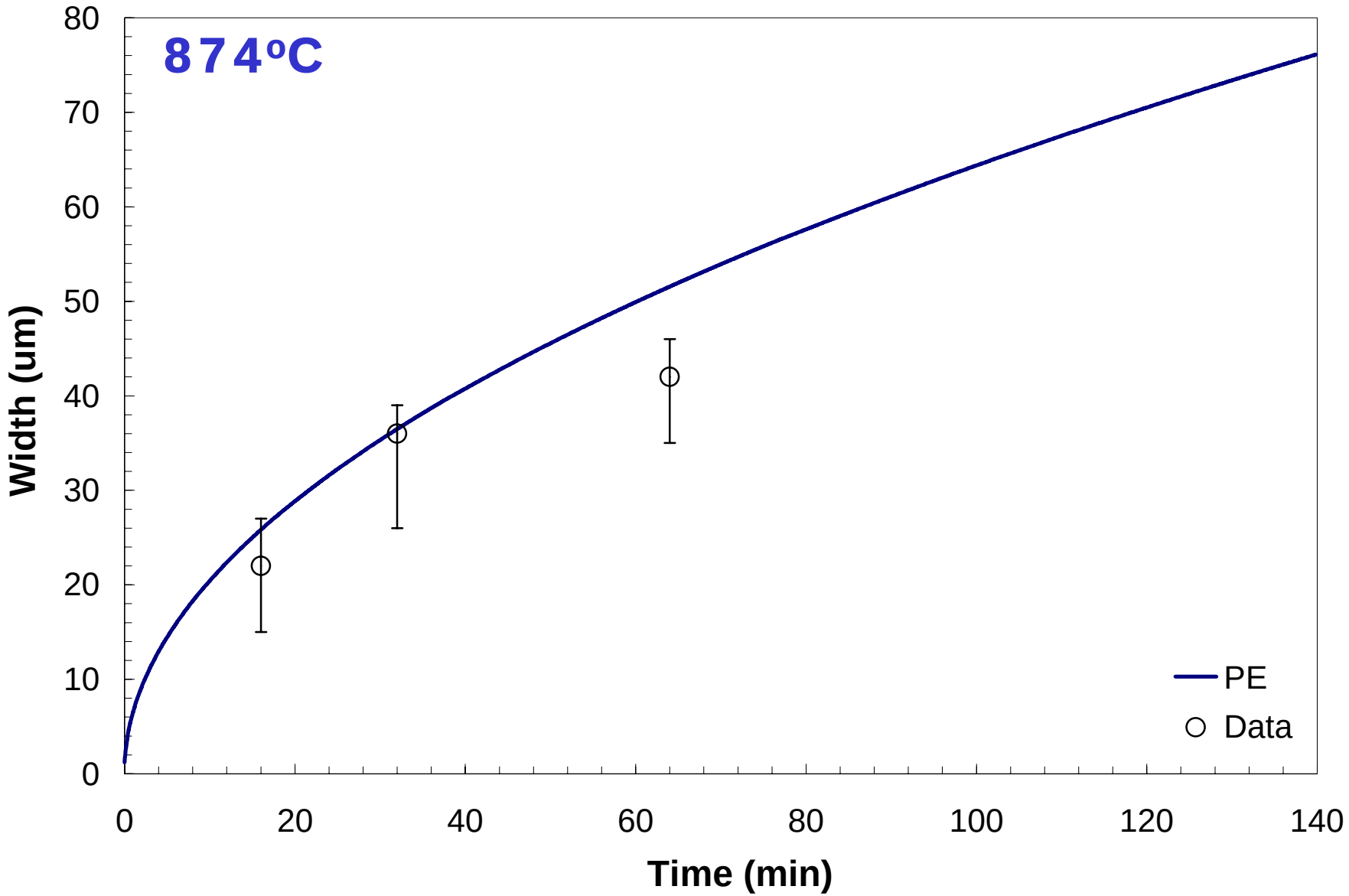
New Results on Fe-Mn-C

- Fe-0.5%Mn-C: Paraequilibrium at high Temperatures, unclear at low T.
- Fe-1%Mn-C: Definite transition from LENP to PE as the temperature increases.
- Fe-2%Mn-C: Ferrite forms above the LENP limit, but at a rate smaller than that predicted by PE.

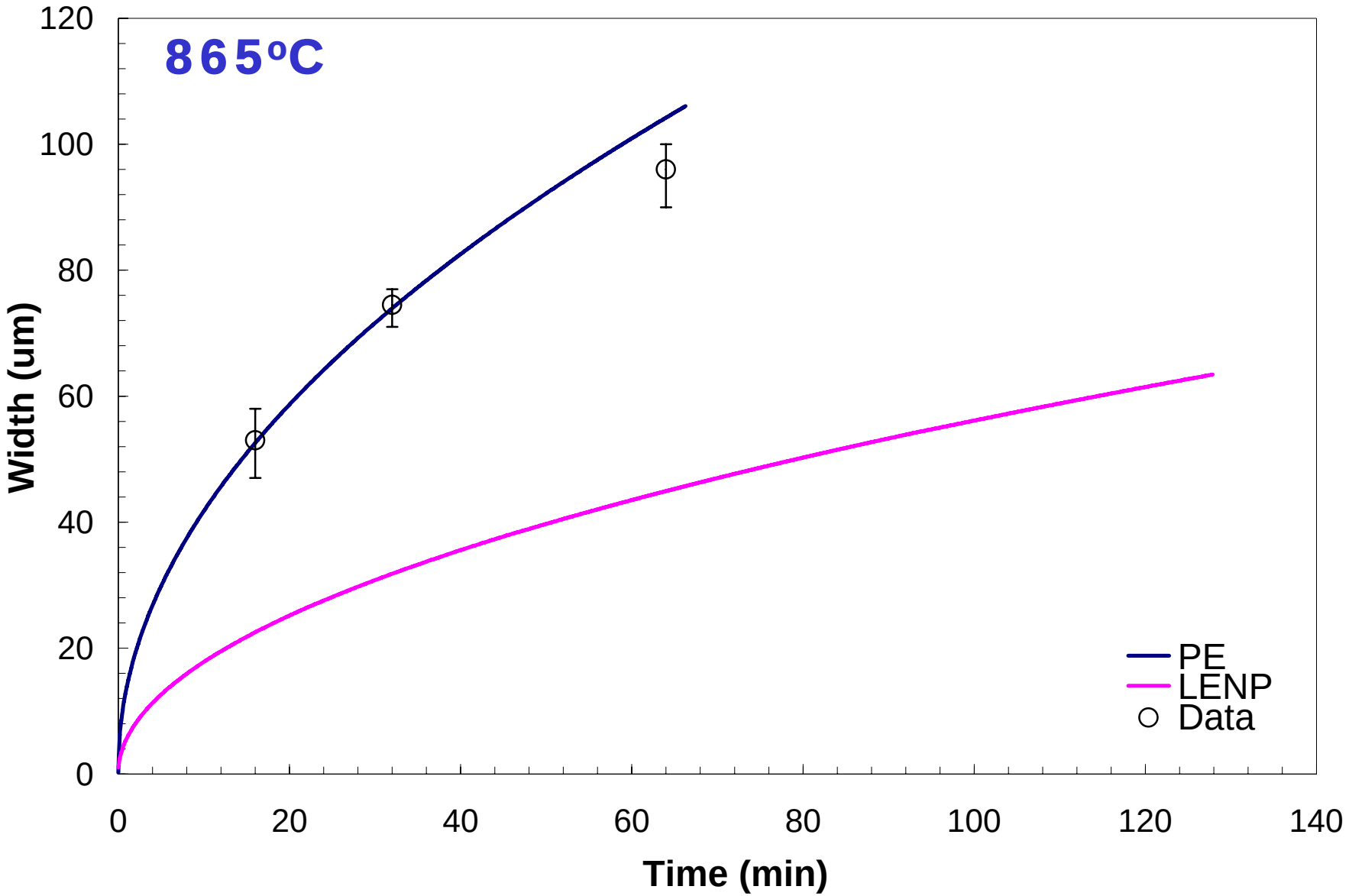
Fe-0.5%Mn-C


1300
1200
1100
1000
900
800
700
T (K)
0
1
2
3
4
5
6
10-3
W(C)
874ºC
865ºC
765ºC

Fe-C-Mn: 0.48%Mn-0.54%C



Fe-C-Mn: 0.48%Mn-0.54%C

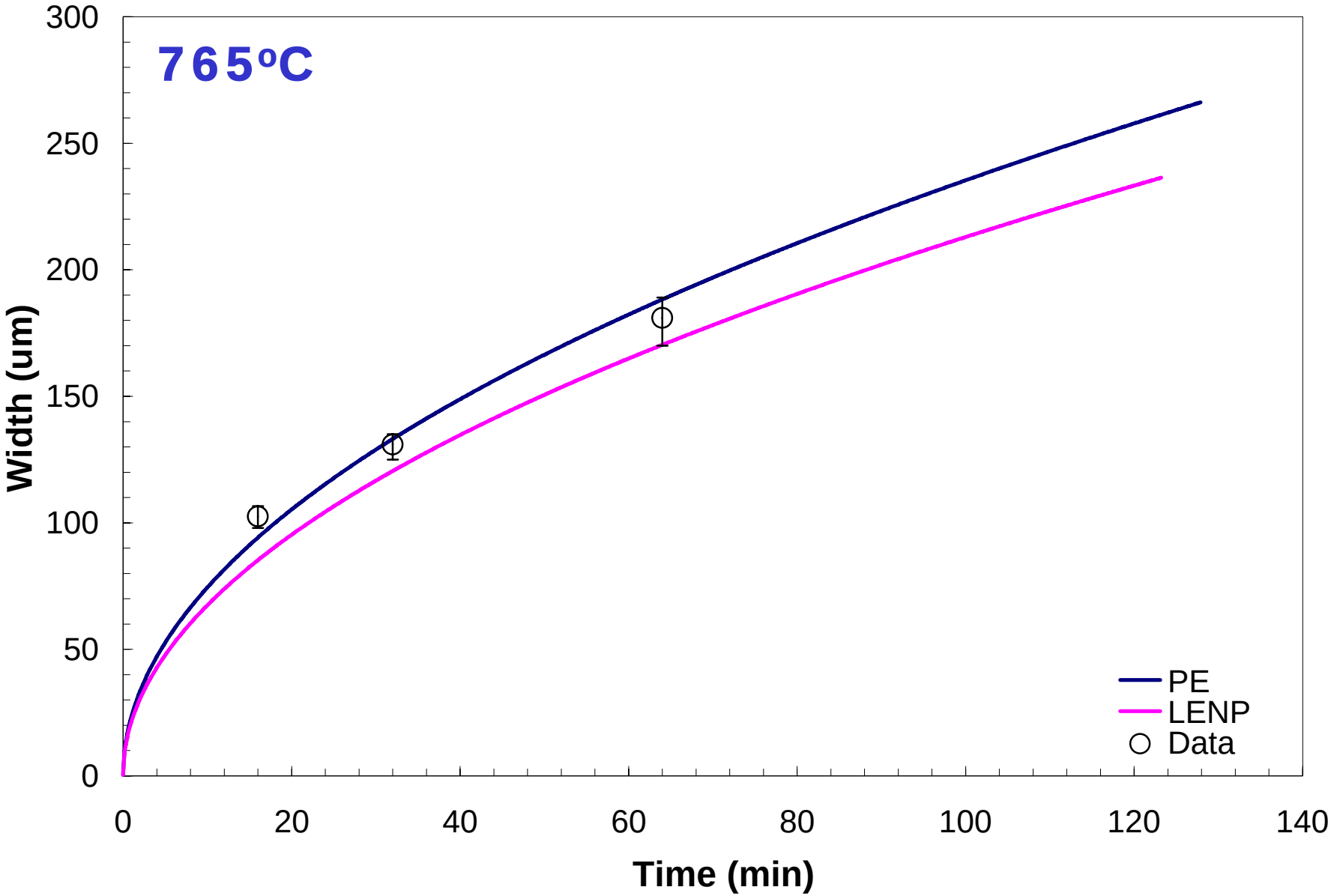


Fe-C-Mn: 0.40%Mn-0.38%C

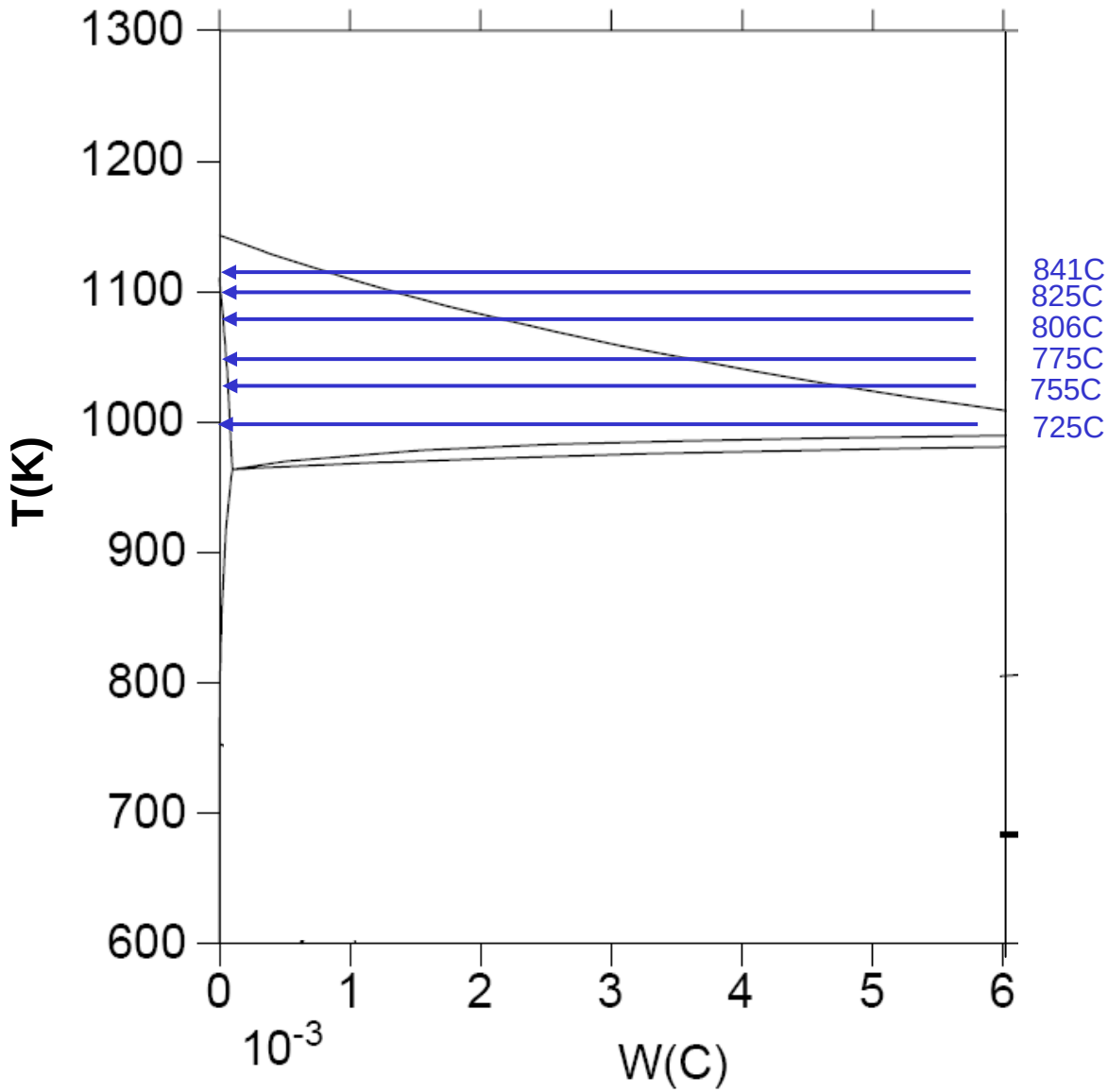
838°C, 32min, PE

810°C, 32min, PE

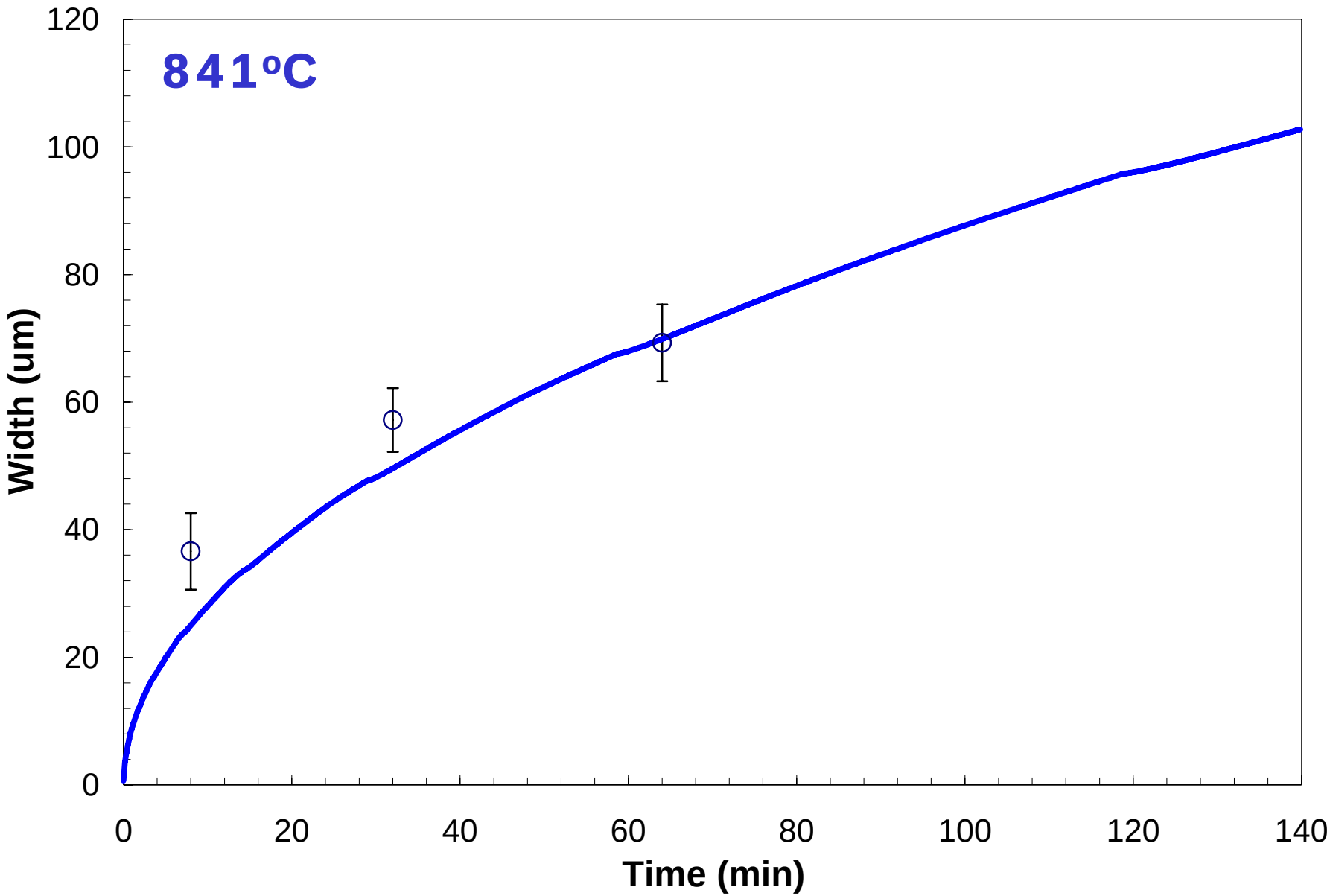
Fe-C-Mn: 0.48%Mn-0.54%C



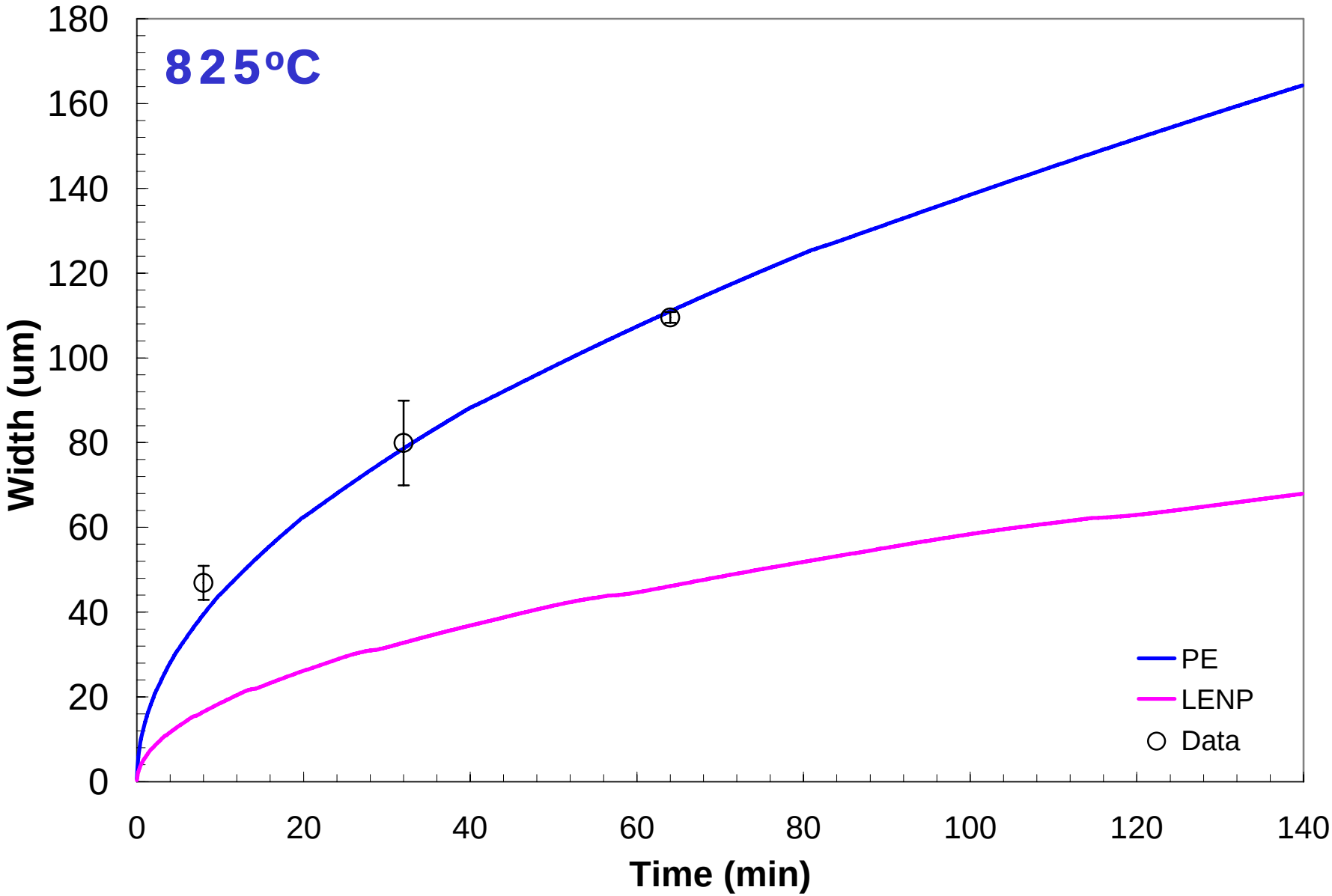
Fe-1%Mn-C


1300
1200
1100
1000
900
800
700
600
T(K)
0
1
2
3
4
5
6
10-3
W(C)
841C
825C
806C
775C
755C
725C

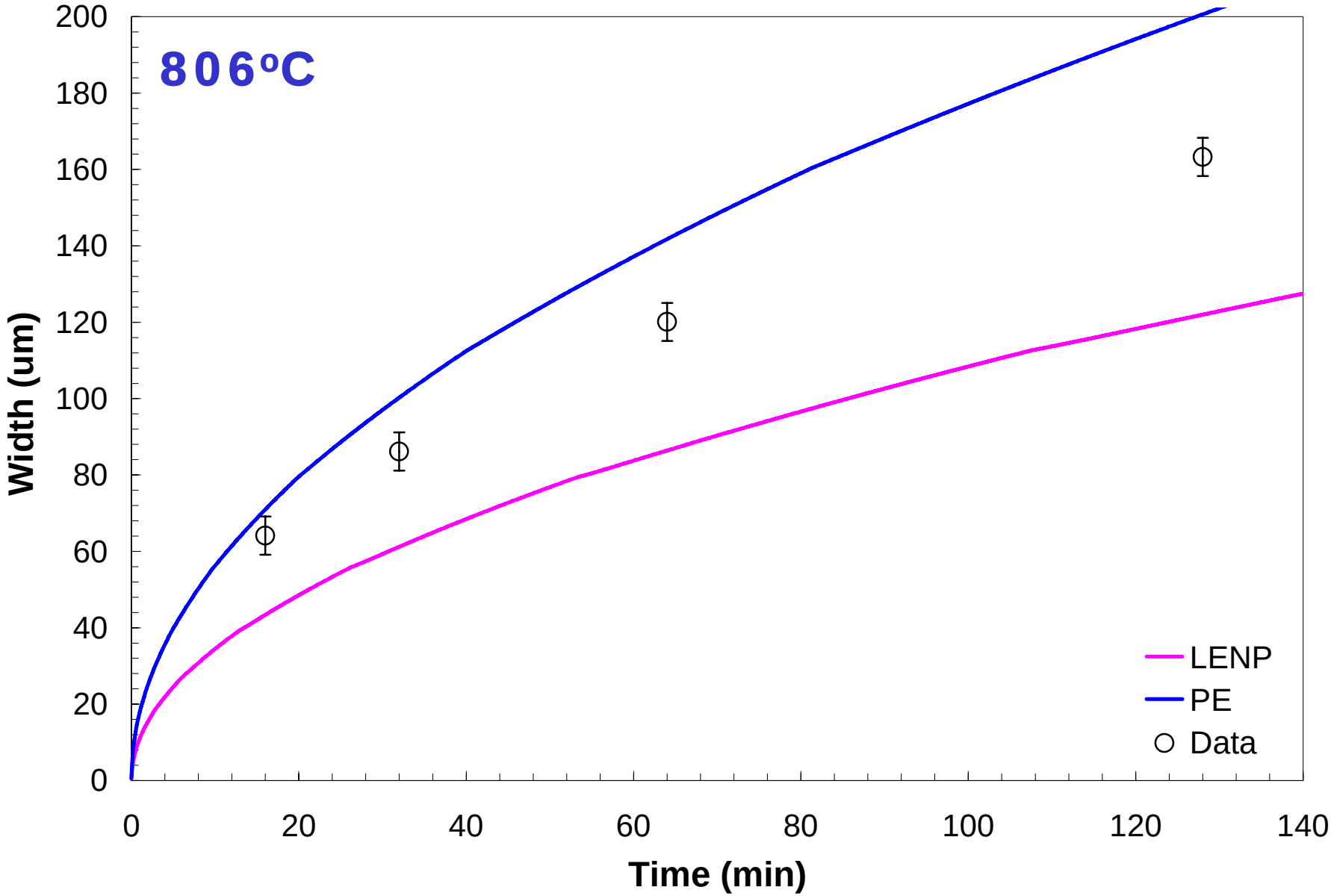
Fe-C-Mn: 0.94%Mn-0.57%C



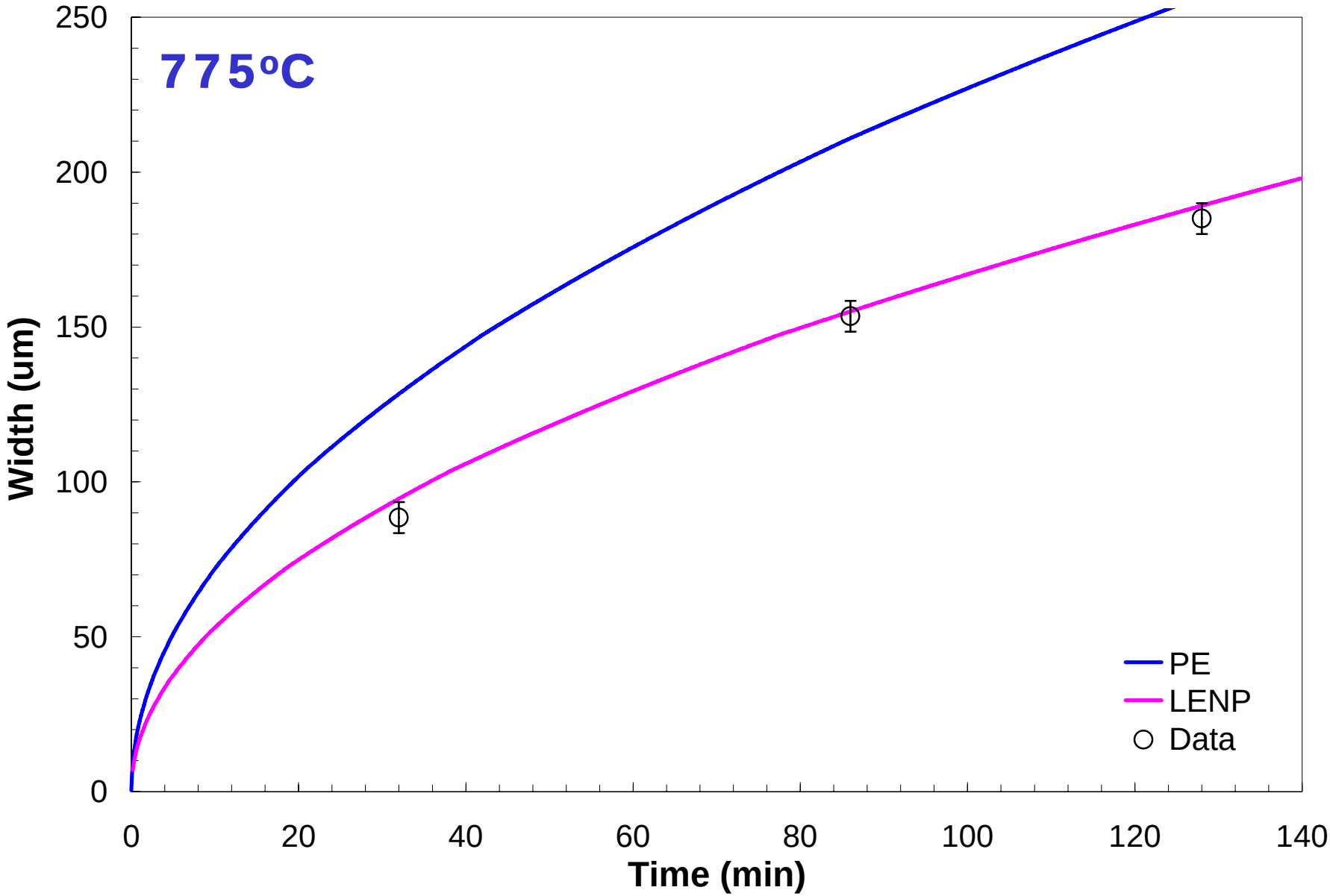
Fe-C-Mn: 0.94%Mn-0.57%C



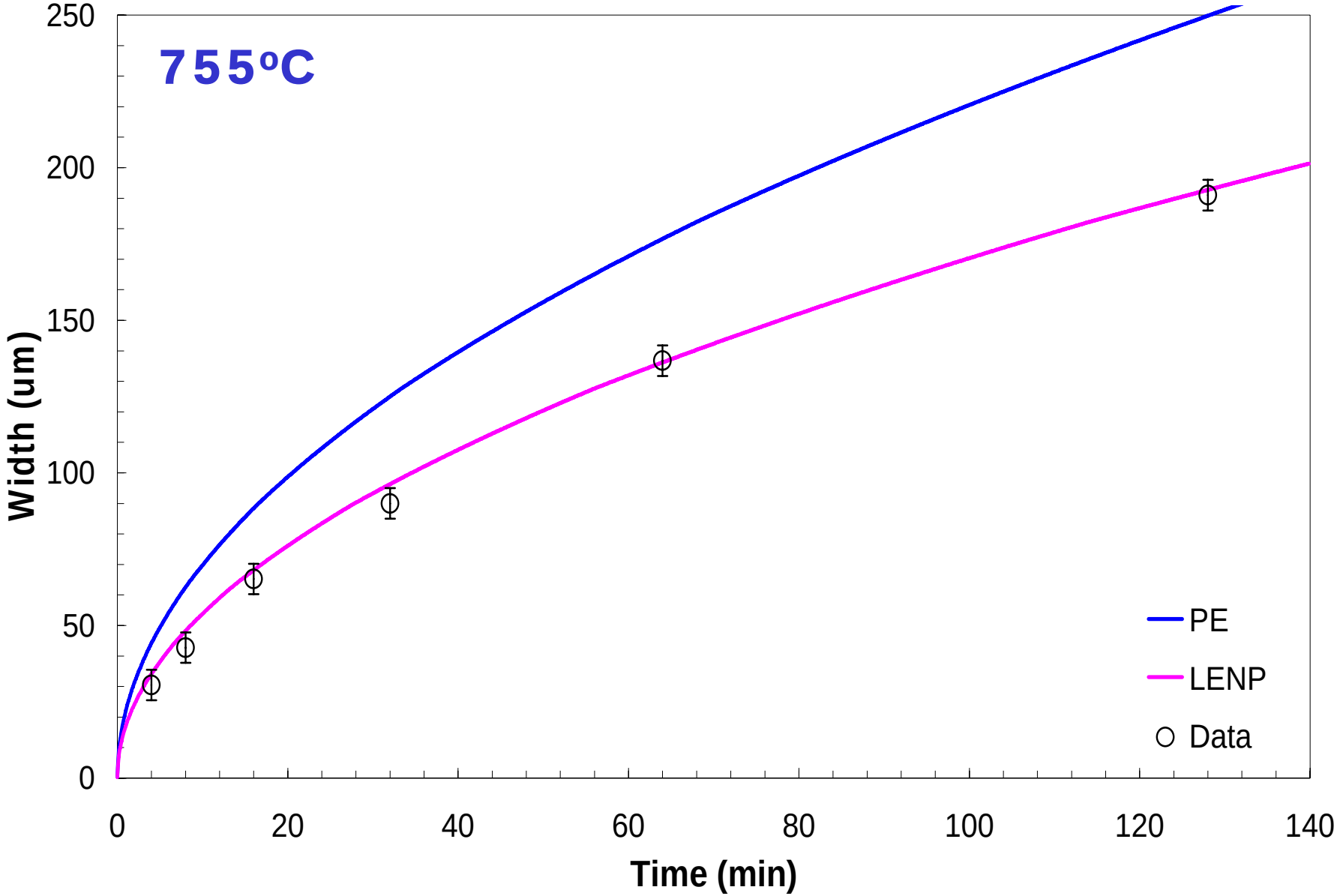
Fe-C-Mn: 0.94%Mn-0.57%C



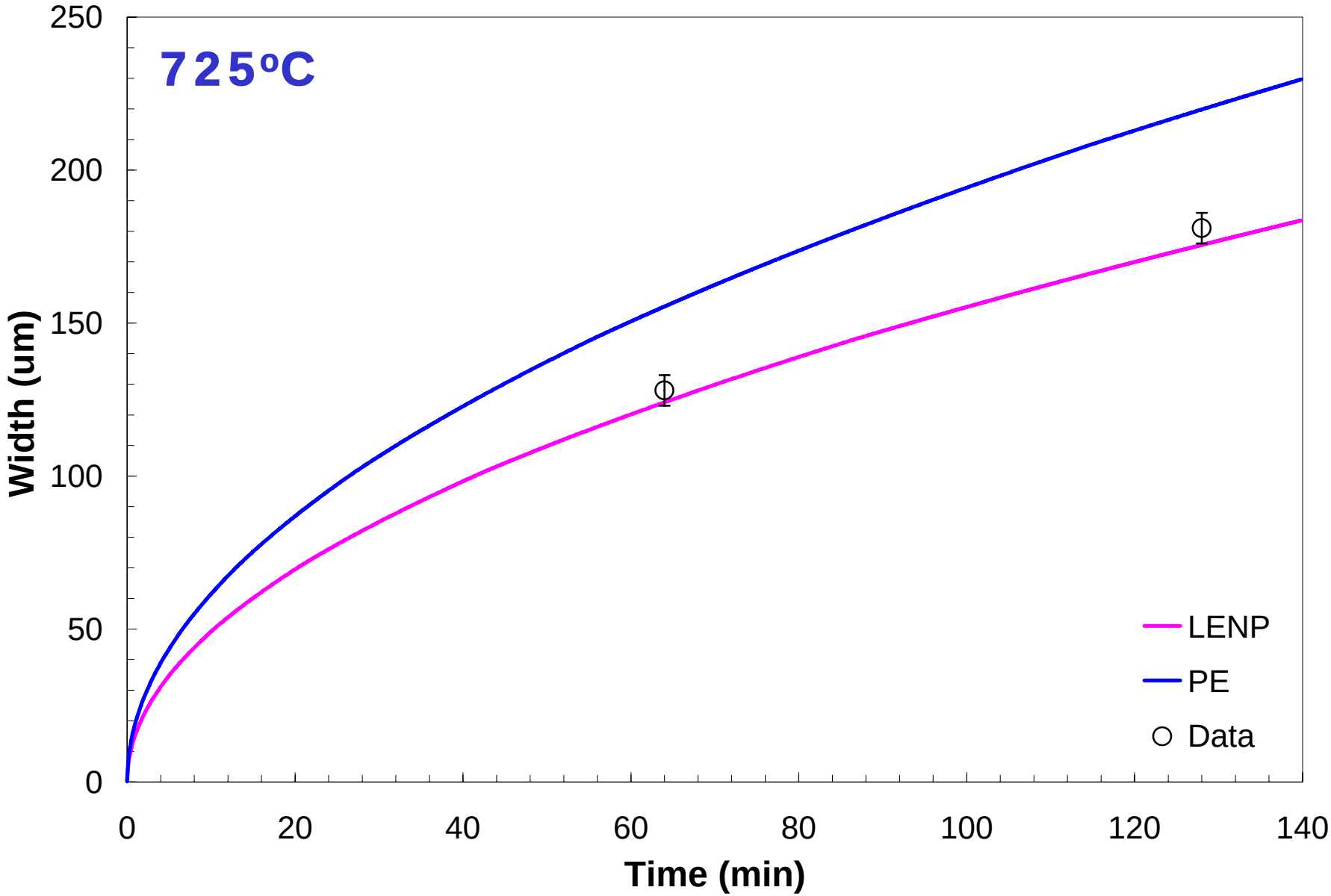
Fe-C-Mn: 0.94%Mn-0.57%C



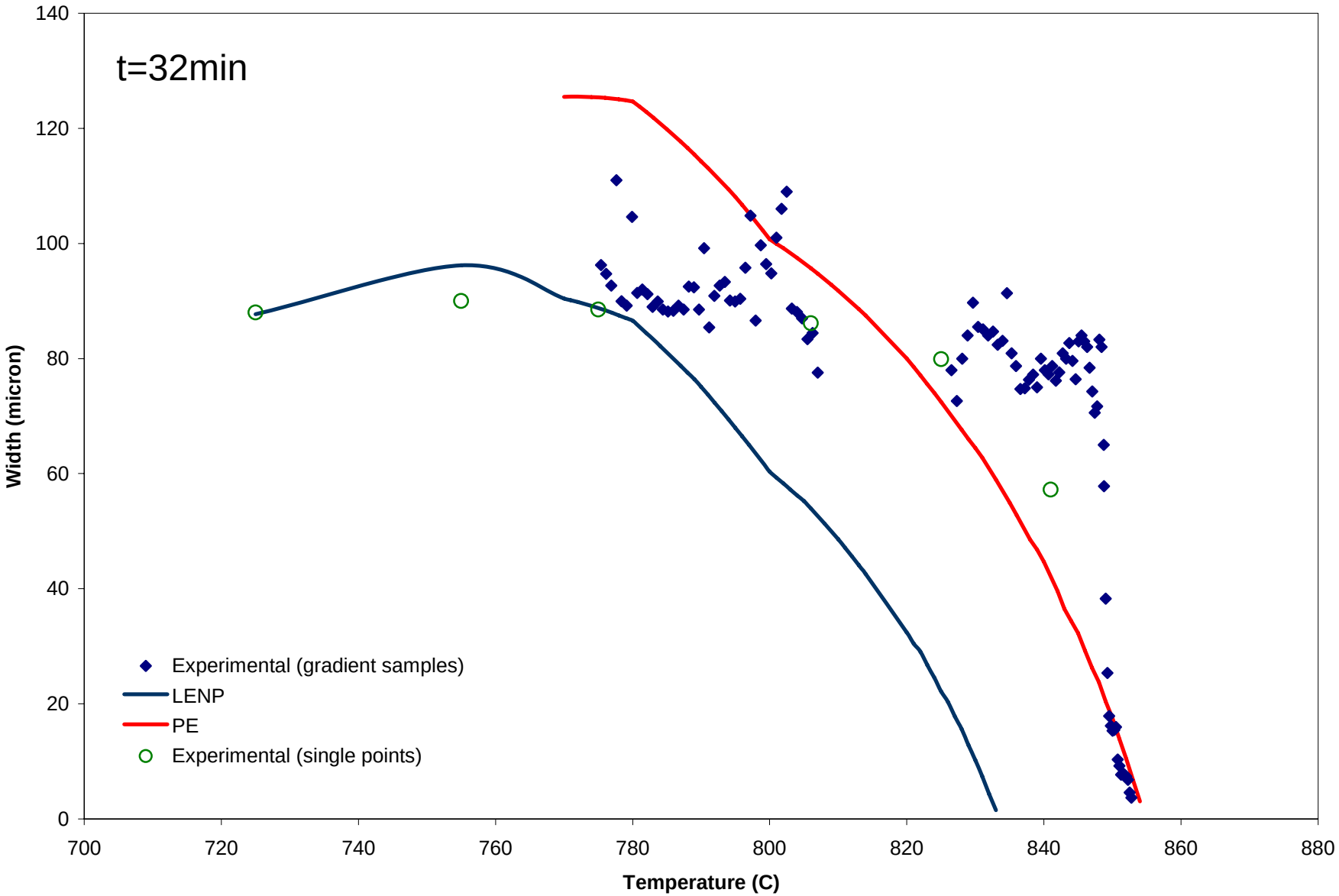
Fe-C-Mn: 0.94%Mn-0.57%C



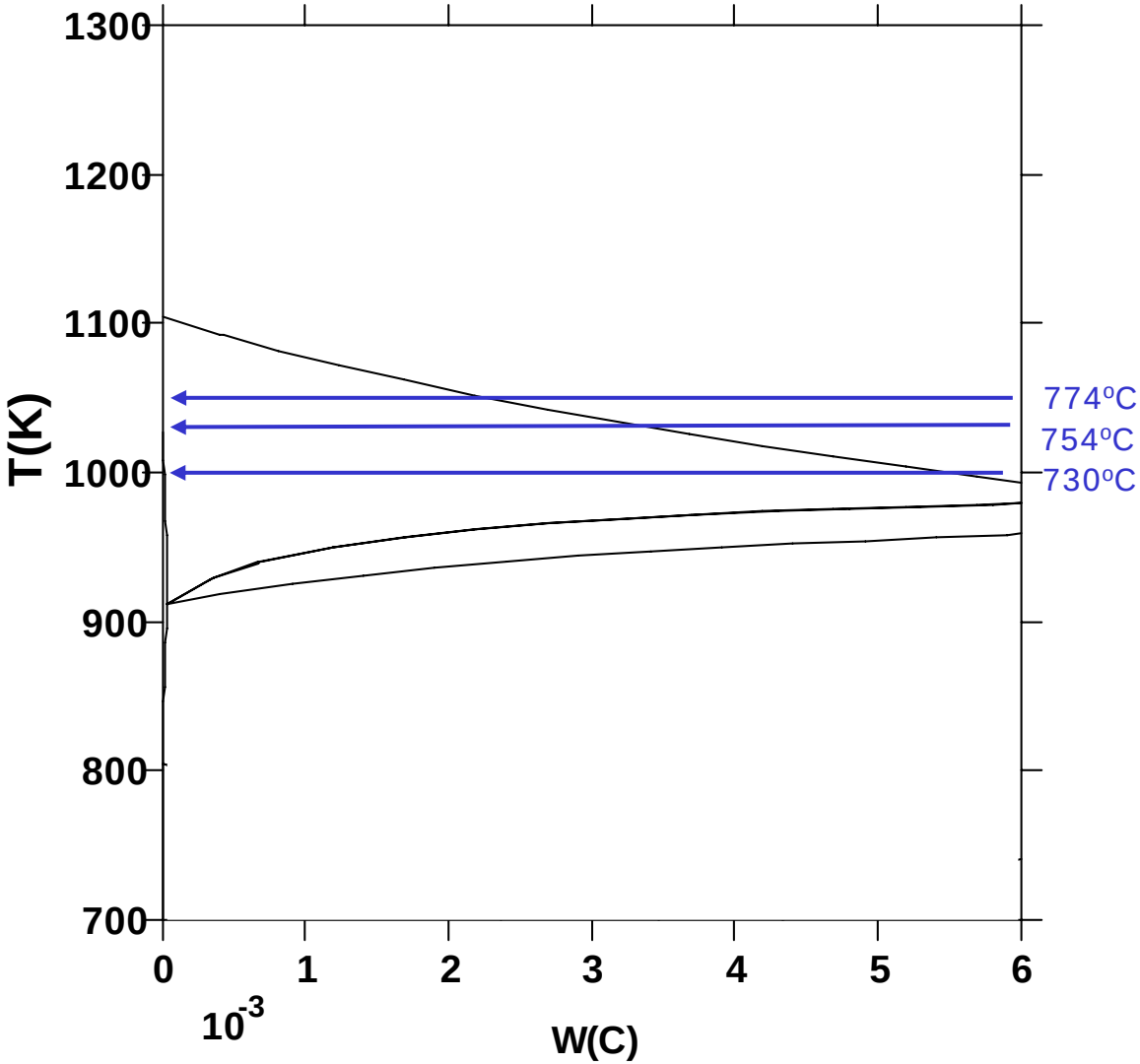
Fe-C-Mn: 0.94%Mn-0.57%C



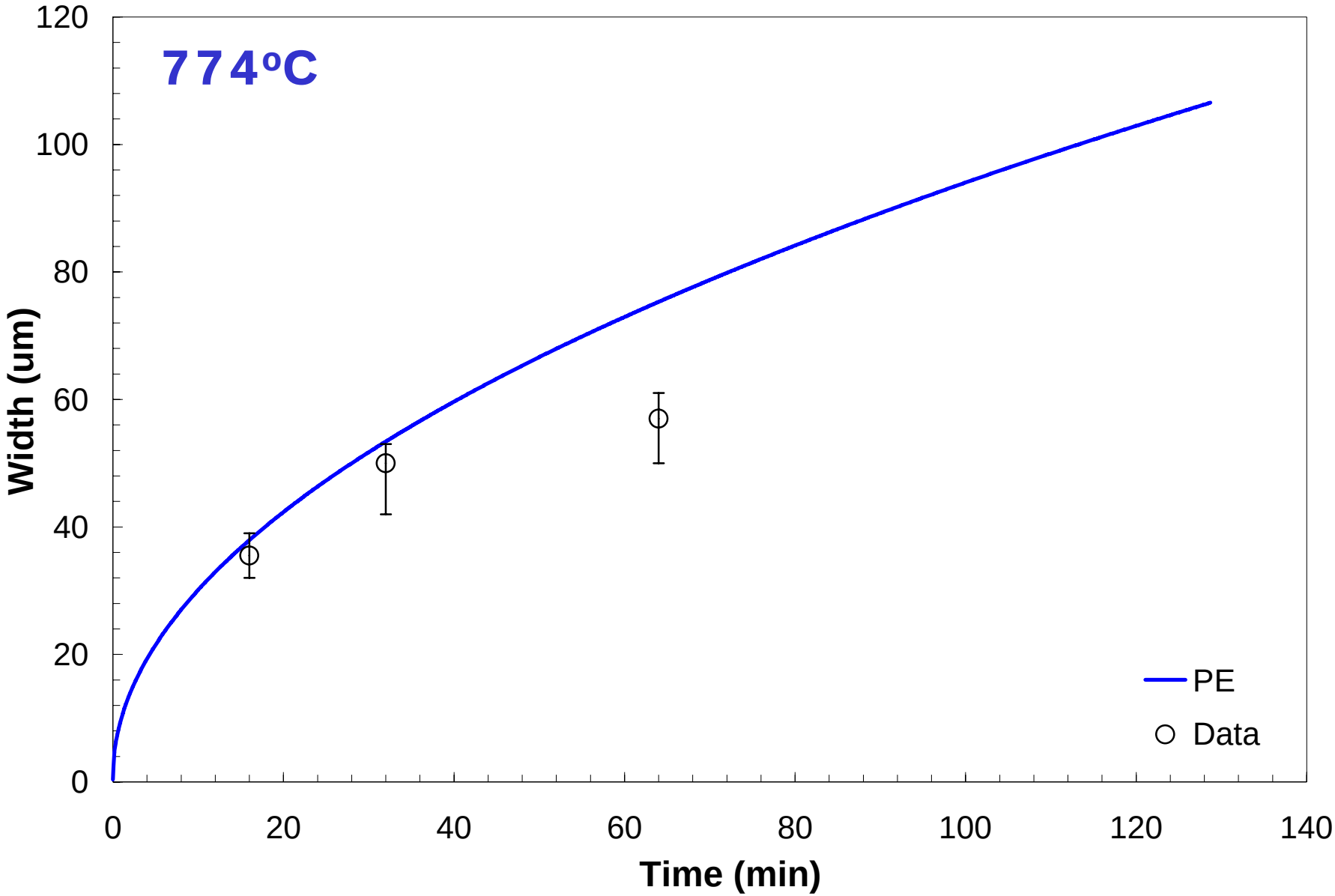
Blue dots show experimental data obtained by decarburizing a long sample in a temperature gradient for 32 min.



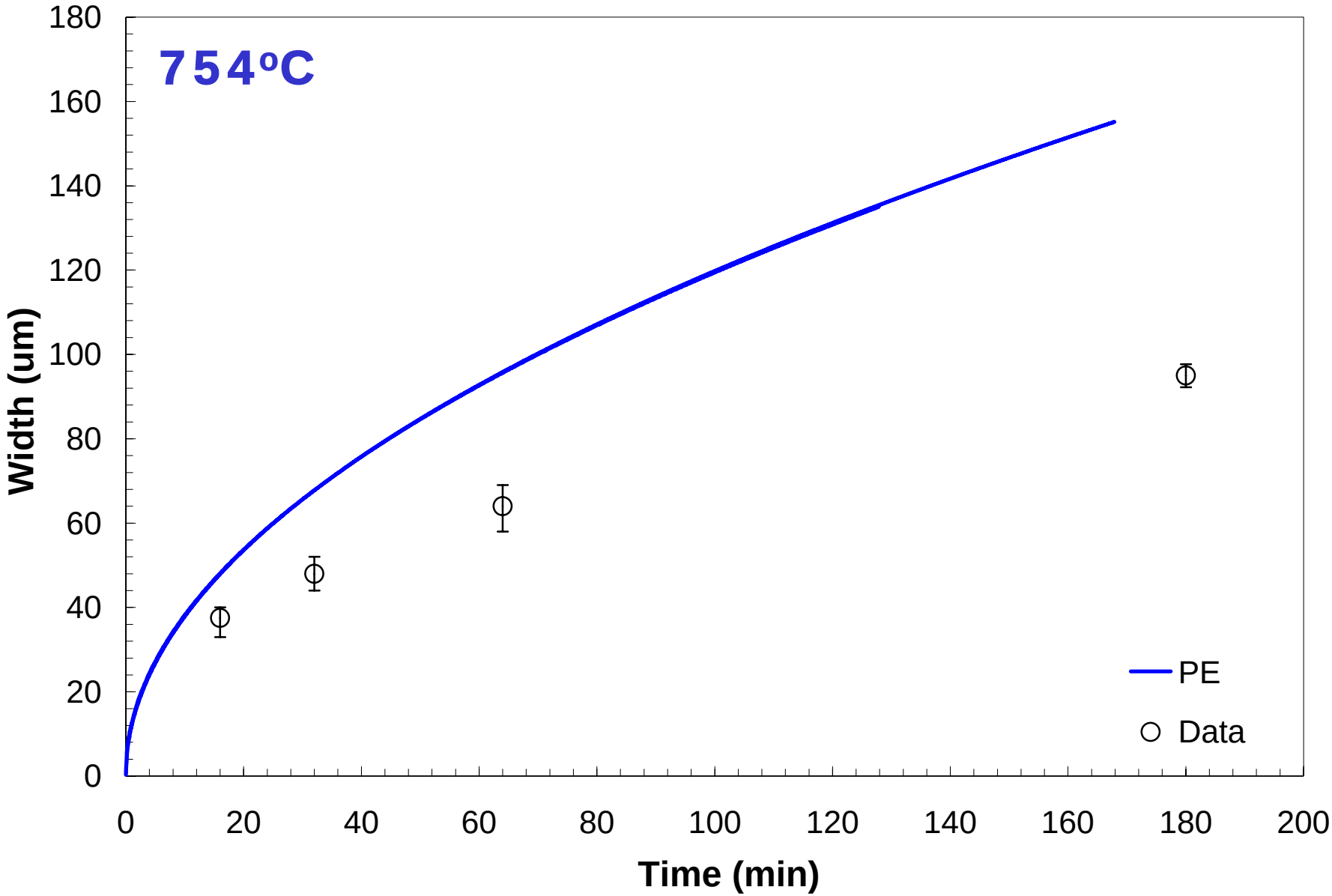
Fe-2%Mn-C


1300
1200
1100
1000
900
800
700
T(K)
774°C
754°C
730°C
0
1
2
3
4
5
6
10-3
W(C)

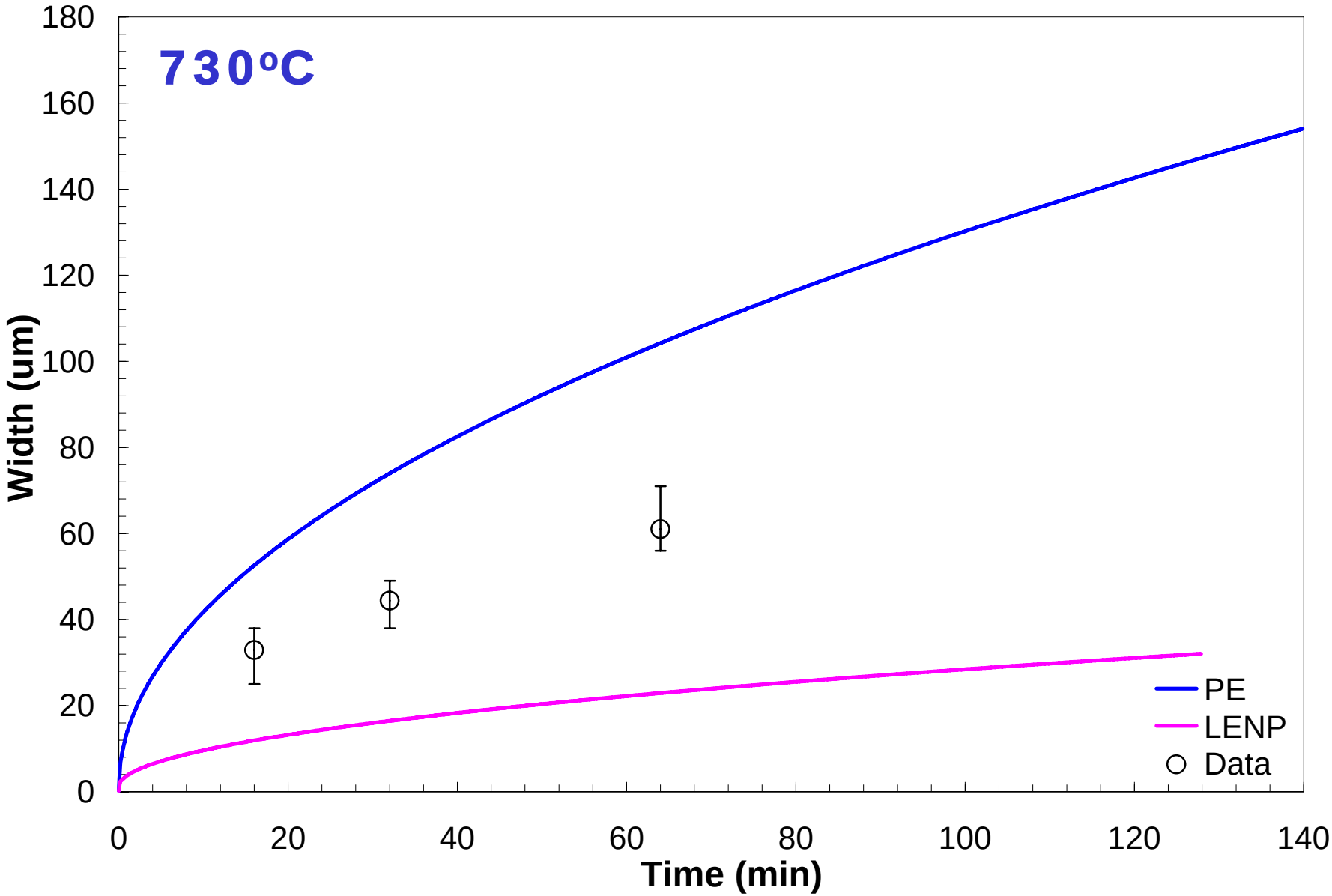
Fe-C-Mn: 2%Mn-0.6%C



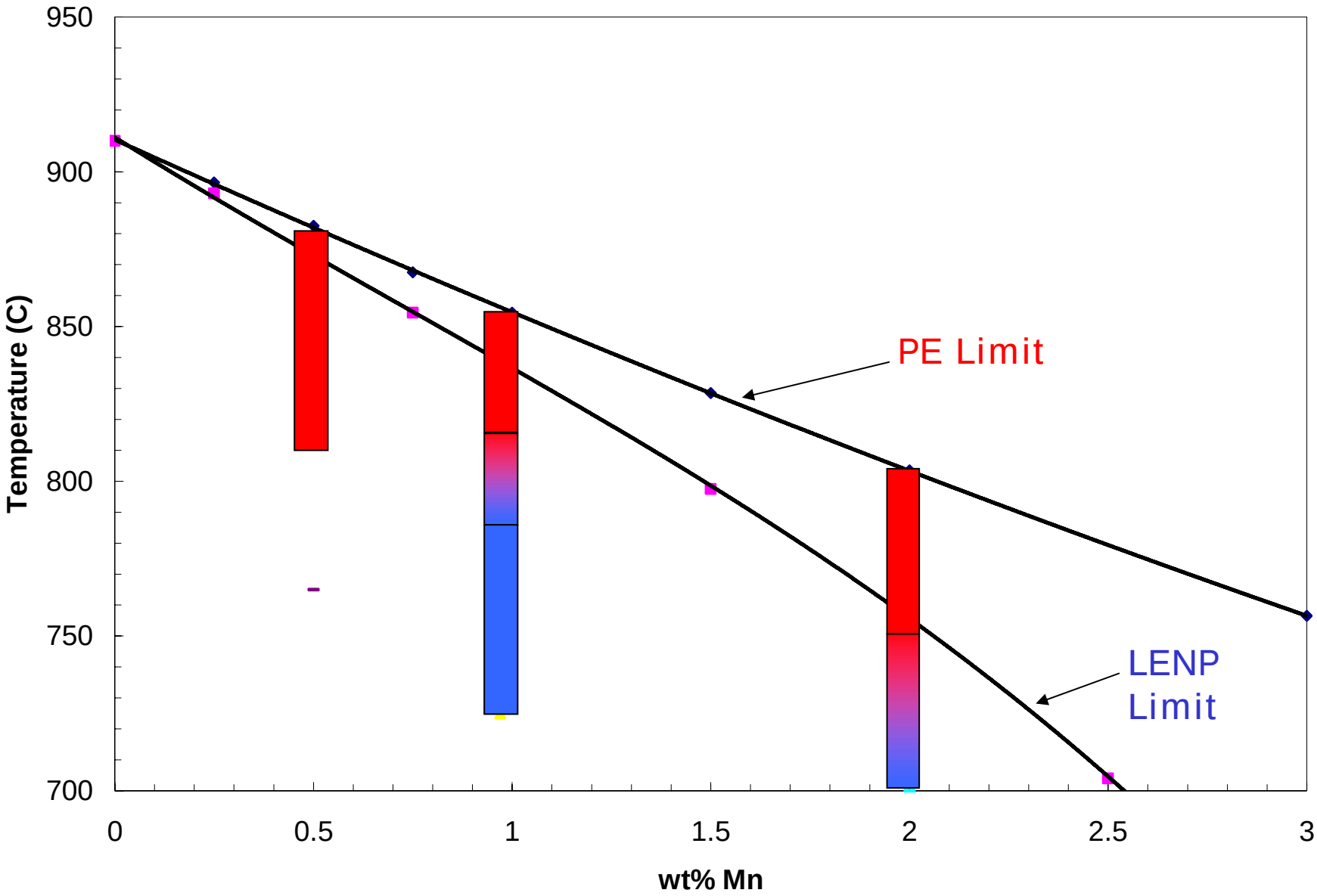
Fe-C-Mn: 2%Mn-0.6%C



Fe-C-Mn: 2%Mn-0.6%C



Fe-C-Mn: T vs. Mn content map

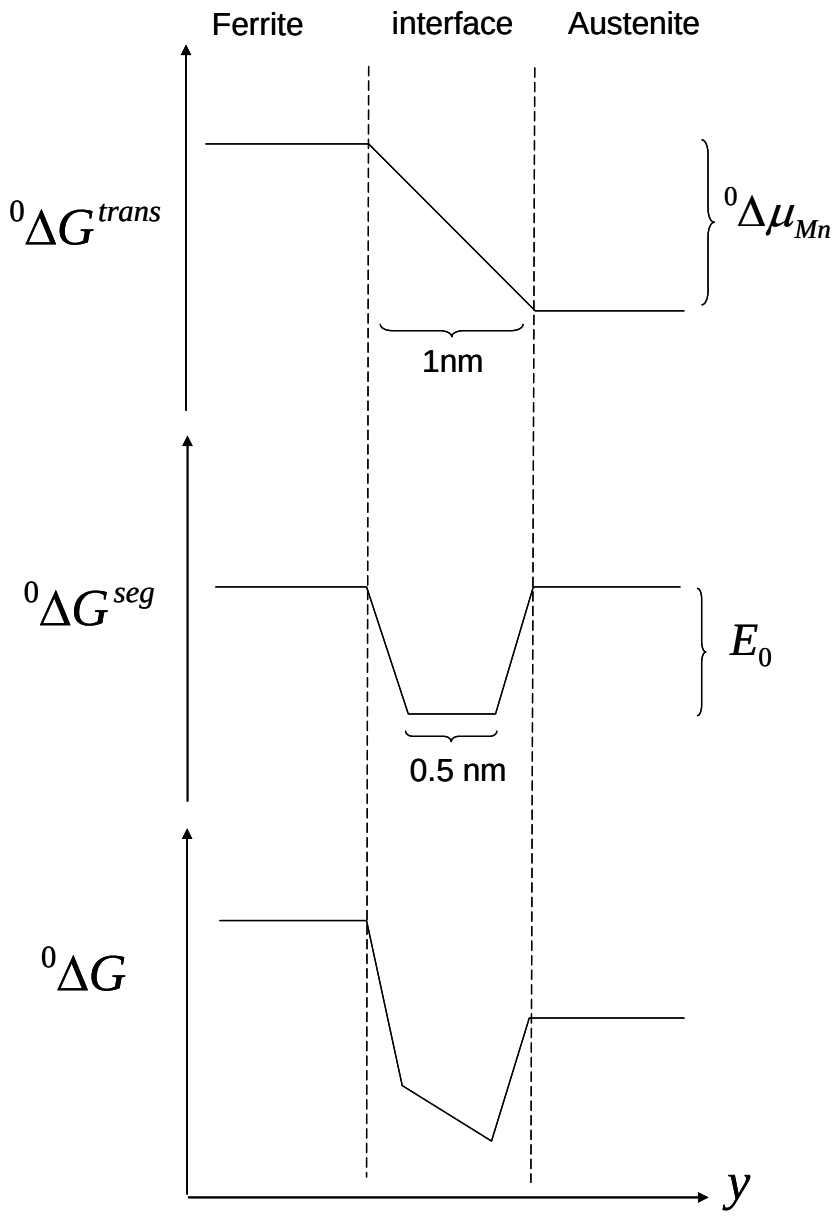


Possible Interpretations

- We need an interpretation that accounts for:
  - Difference between the behaviors of Fe-Mn-C and Fe-Ni-C.
  - Accounts for the transition between PE and LENP.
  - Explains long-lived intermediate states between LENP and PE.

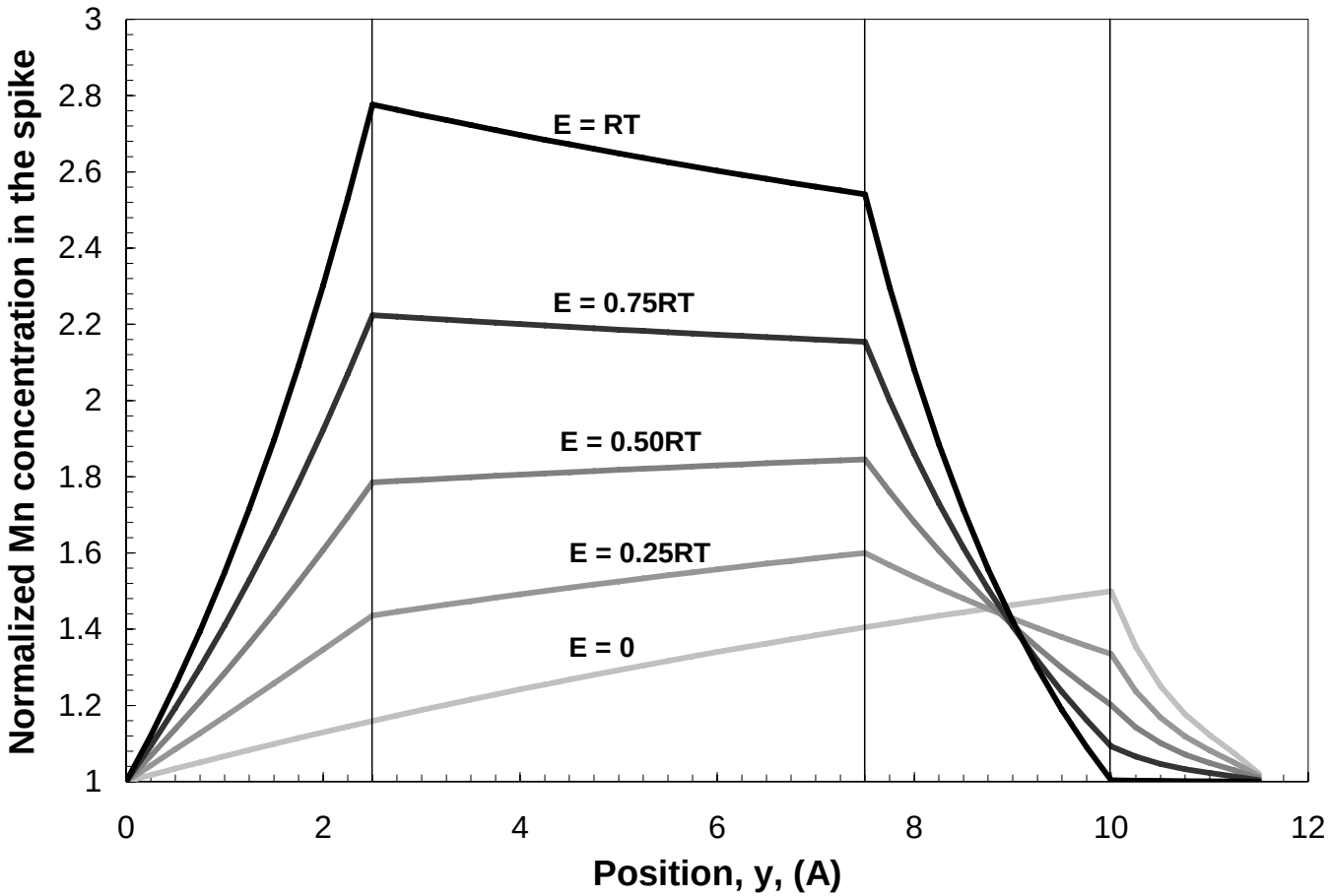
Possible Interpretations

- Important Role of Segregation:



Possible Interpretations

- Important Role of Segregation:



Challenges:

- Temperature dependence is problematic:
  - As T increases, segregation should become weaker. At the same time D become larger. Both factors should favor LENP at high T.
- Concentration dependence is also difficult to explain.
- Solute Drag
  - Segregation would lead to the development of solute drag.

Conclusions:

- Kinetic transitions are observed in the Fe-Mn-C system during decarburization.
- It appears that segregation to the interface plays an important role in determining the ferrite growth kinetics.
- Additional modeling is needed to rationalize the data.

Acknowledgements

- Dr. T. Furuhara is gratefully acknowledged for providing the Fe-2%Mn-0.6% Alloy.
- Financial support of ISIJ is gratefully acknowledged.
- This research was funded by the Natural Science and Engineering Research Council (NSERC) of Canada.