Application of thermodynamic modeling to the study of precipitation in IF (interstitial free) steels

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Summary

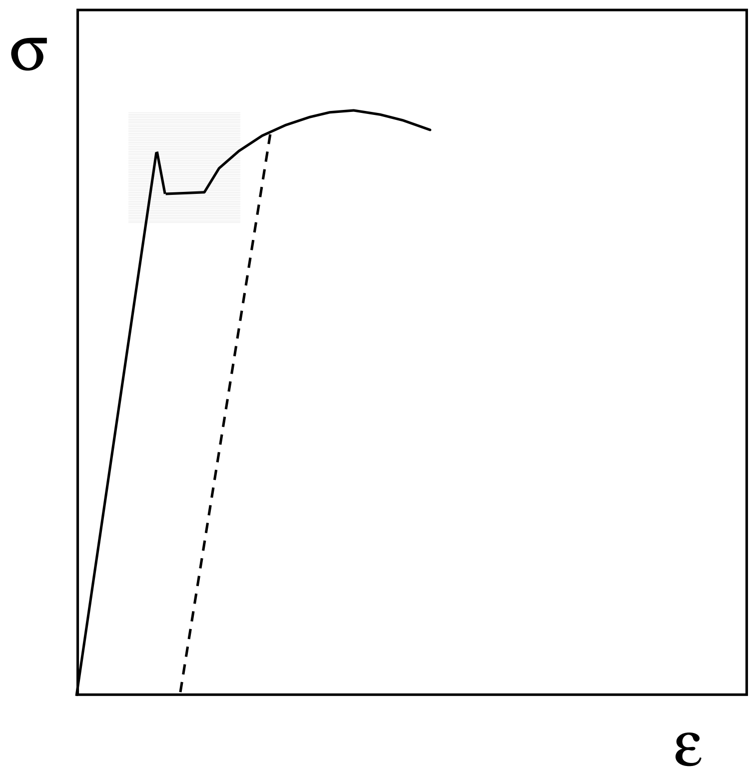
- **Introduction**
- **Steels for Formability**
  - Classical
  - IF
- **IF Strategies**
  - Steelmaking
  - Gettering
- **Current Generation**
  - Which is the best getter?
  - Is it good to have excess getter in solution?
  - How to reach bake hardenability
  - New precipitates?
- **Conclusions**

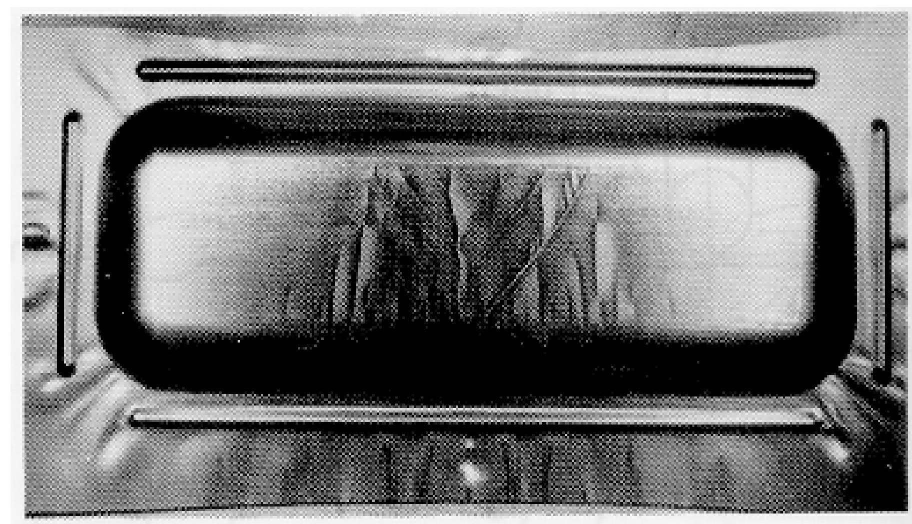
Requirements for Deep Drawing Steel

- **Metallurgical**
  - Low content of interstitial solutes (in solution)
  - Good texture (measured by ***r -*** anisotropy coefficient)
  - High work hardening coefficient
  - Low yield stress

- **Industrial**
  - Low cost
  - High productivity

Ageing- Interstitial Solutes





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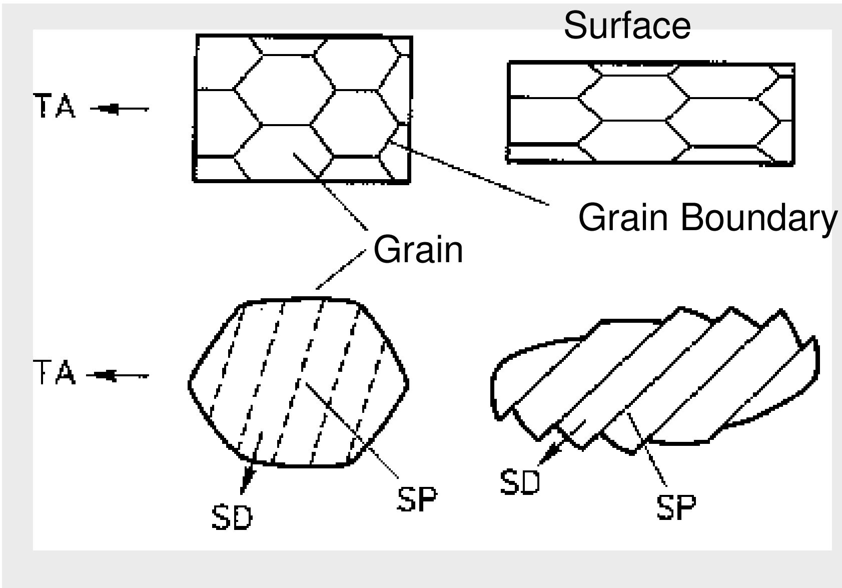
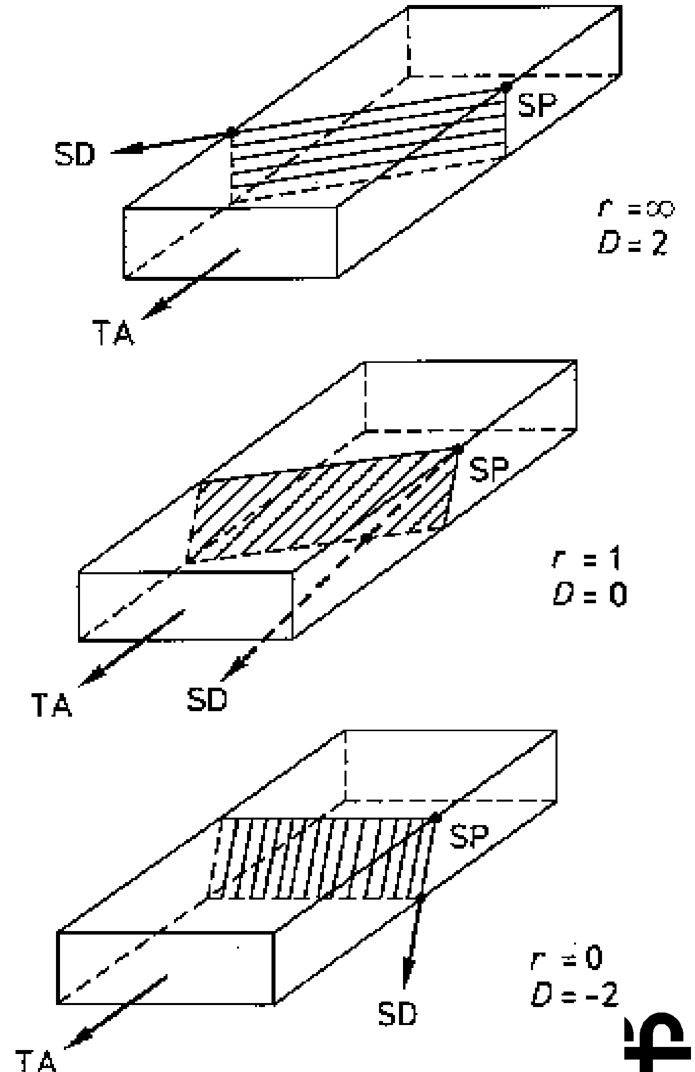
Texture and Formability



Plastic Deformation Ratio
Lankford ***r***

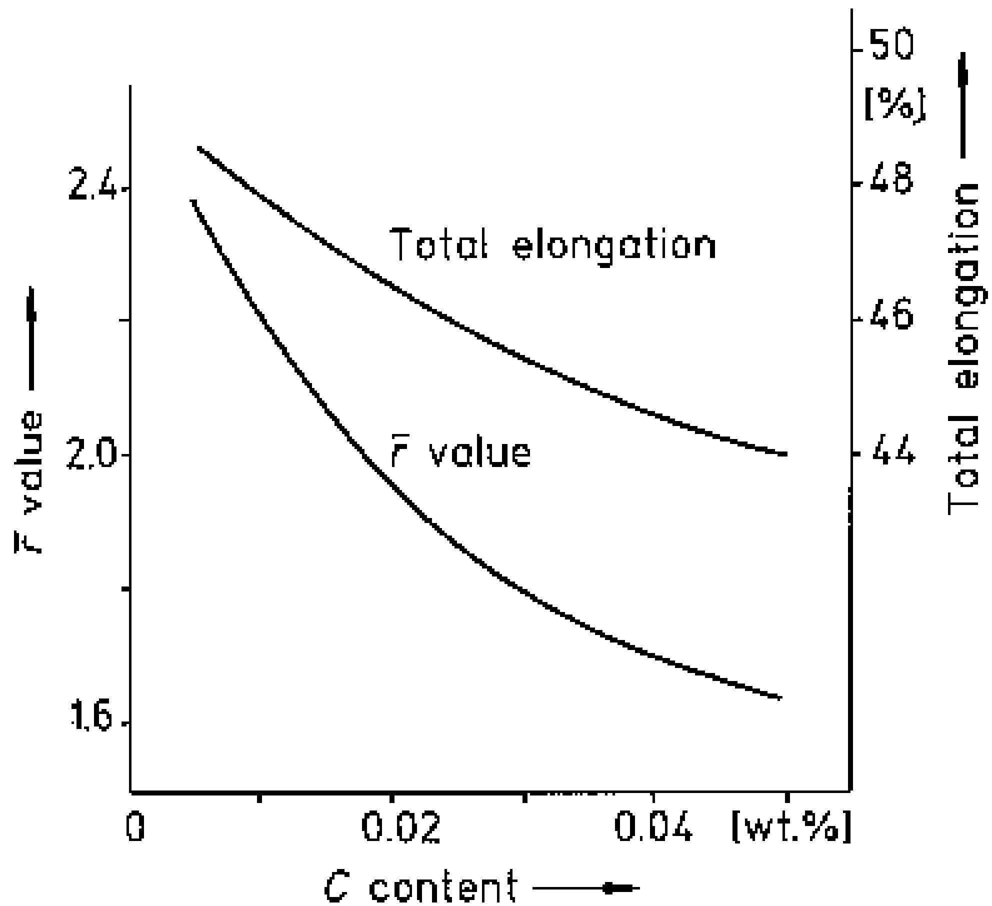
$$r = \frac{\text{width deform.}}{\text{thickness def.}} = \frac{\ln \frac{w}{w_o}}{\ln \frac{t}{t_o}}$$



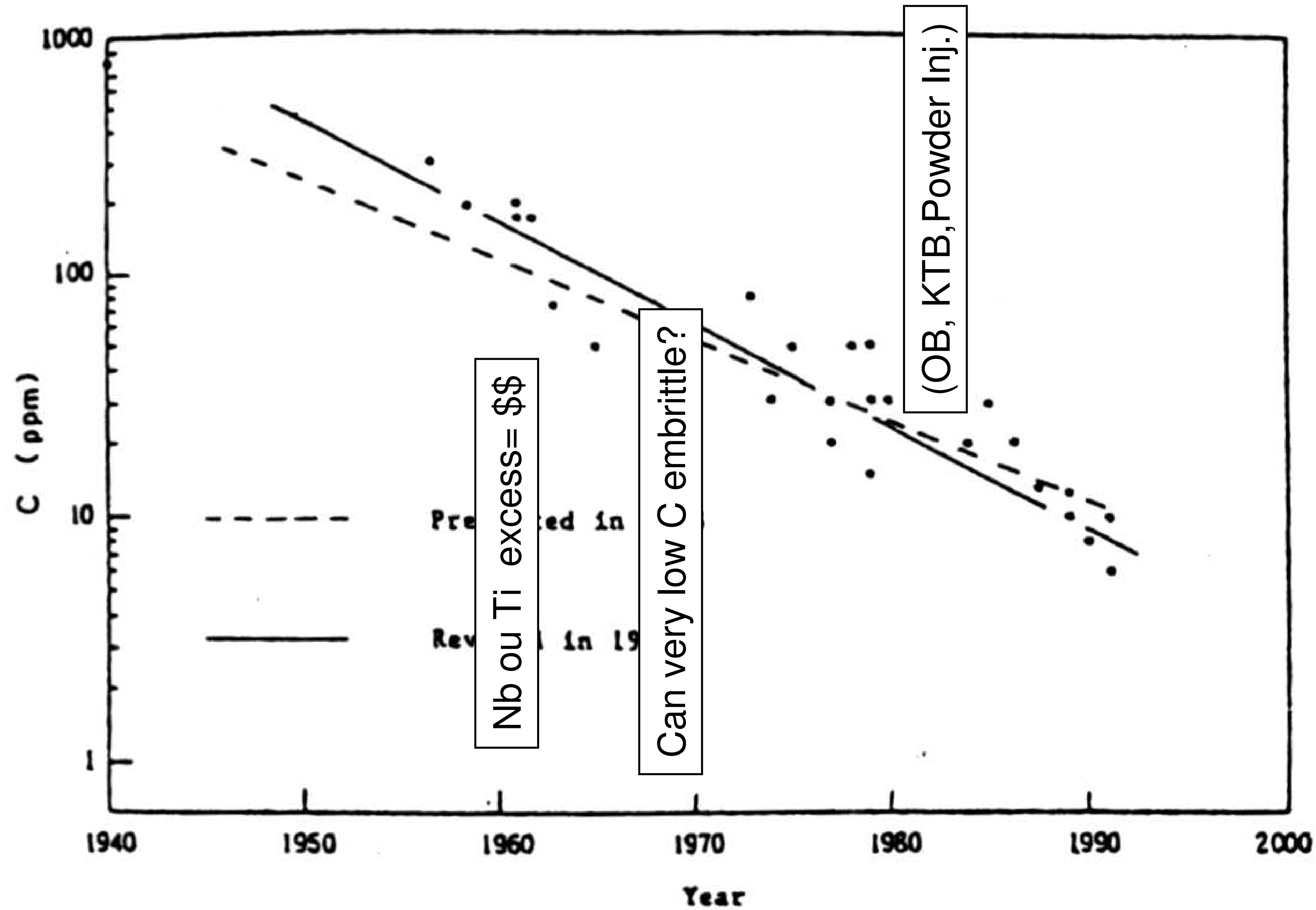
Carbon and Anisotropy of Deformation

$$\bar{r} = \frac{1}{4}(r_0 + 2r_{45} + r_{90})$$

$$\Delta r = \frac{1}{4}(r_0 + r_{90} - 2r_{45})$$



Strategies for Low Carbon



Alloy Design

- **Aging control: minimize C e N in solution.**
- **Texture formation: minimize C e N in solution**
  Sufficient cold work
- **Annealing T and t**

- **Recrystallization control: Control T anneal**
  Control Nb e Ti in solution

- **How to achieve Bake Hardenability?**

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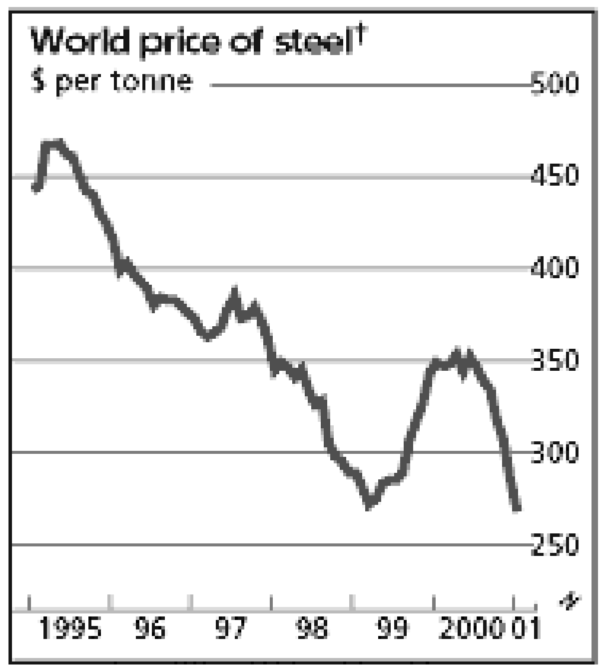
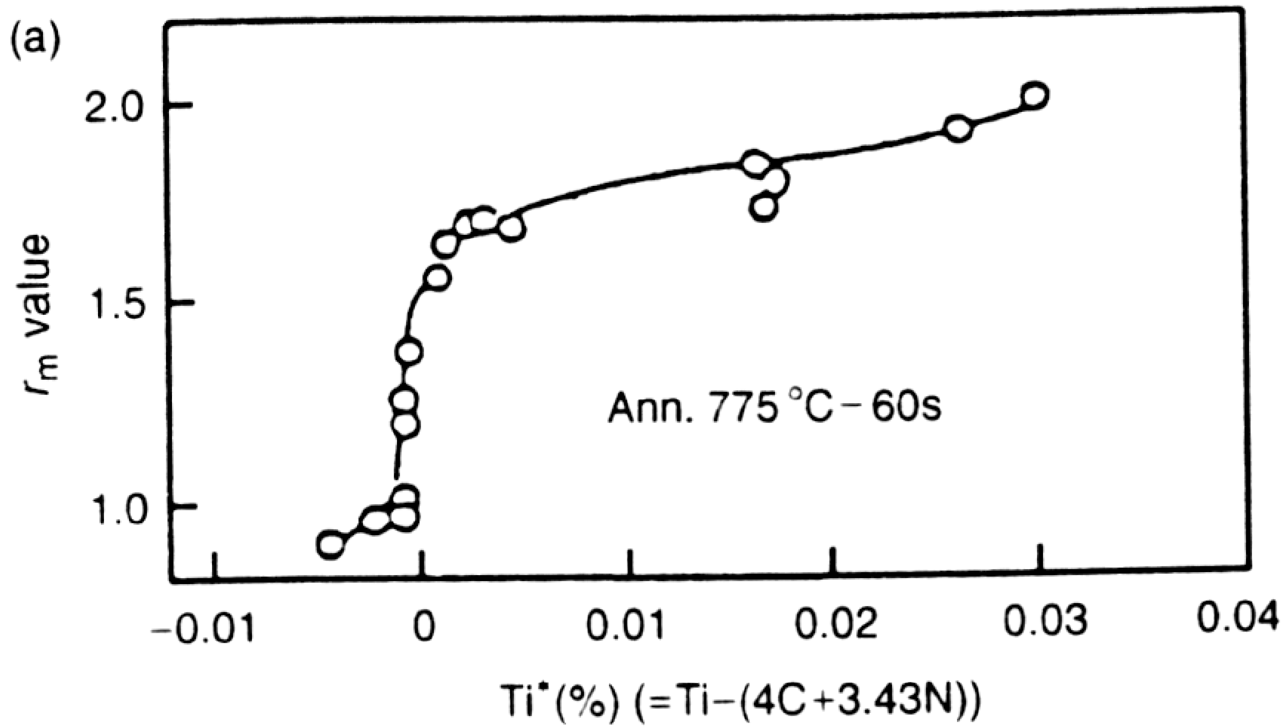
The classical approach

- Carbon tied in cementite
- Nitrogen tied in AlN (see poster!)
- Control of stage of precipitation depending on type of processing. Control of recrystallization.
- "Classical" deep drawing steel is back! ($$$)



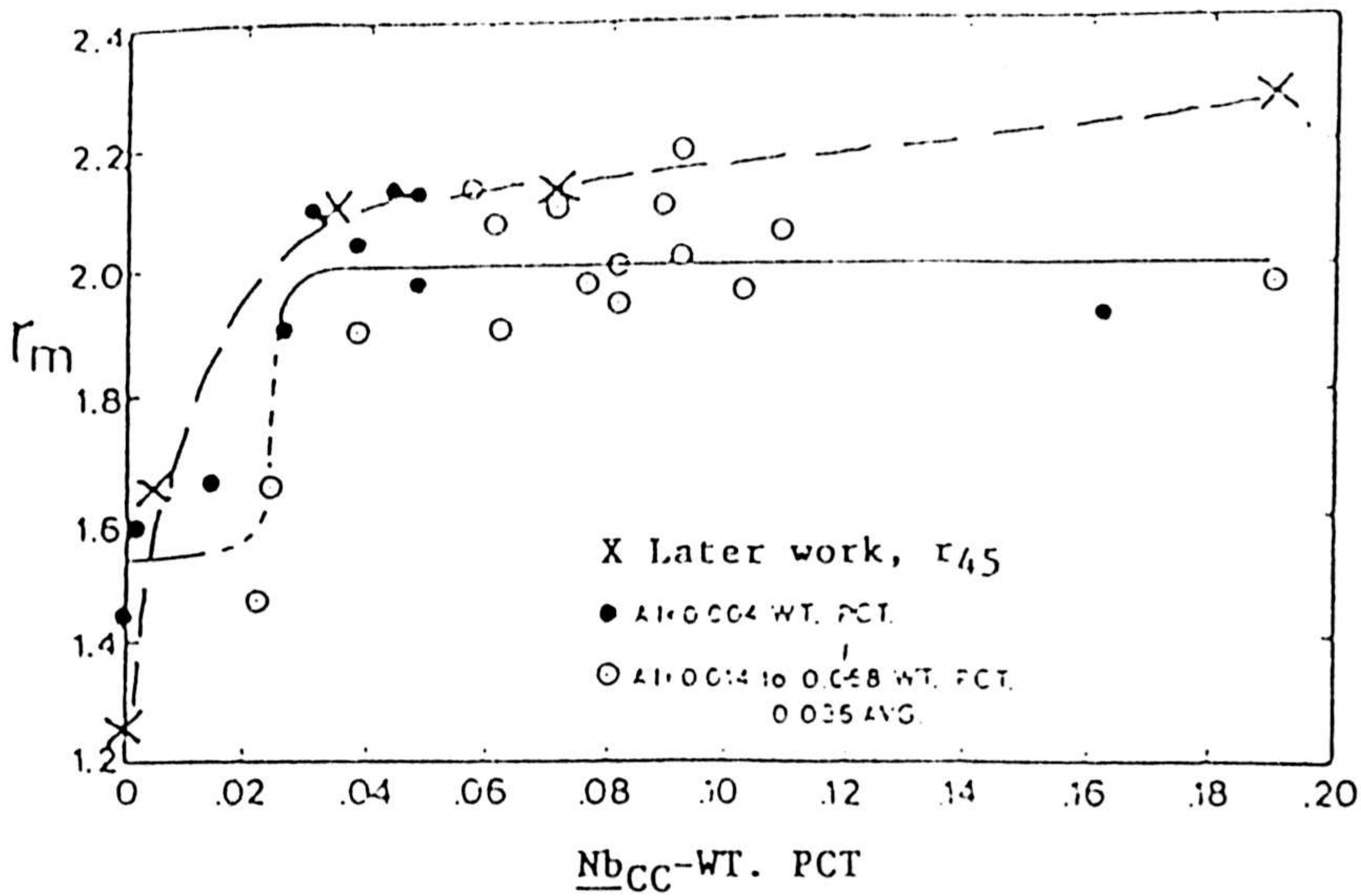
merger goes ahead †Hot rolled coil, highest price

Which getter? Ti?

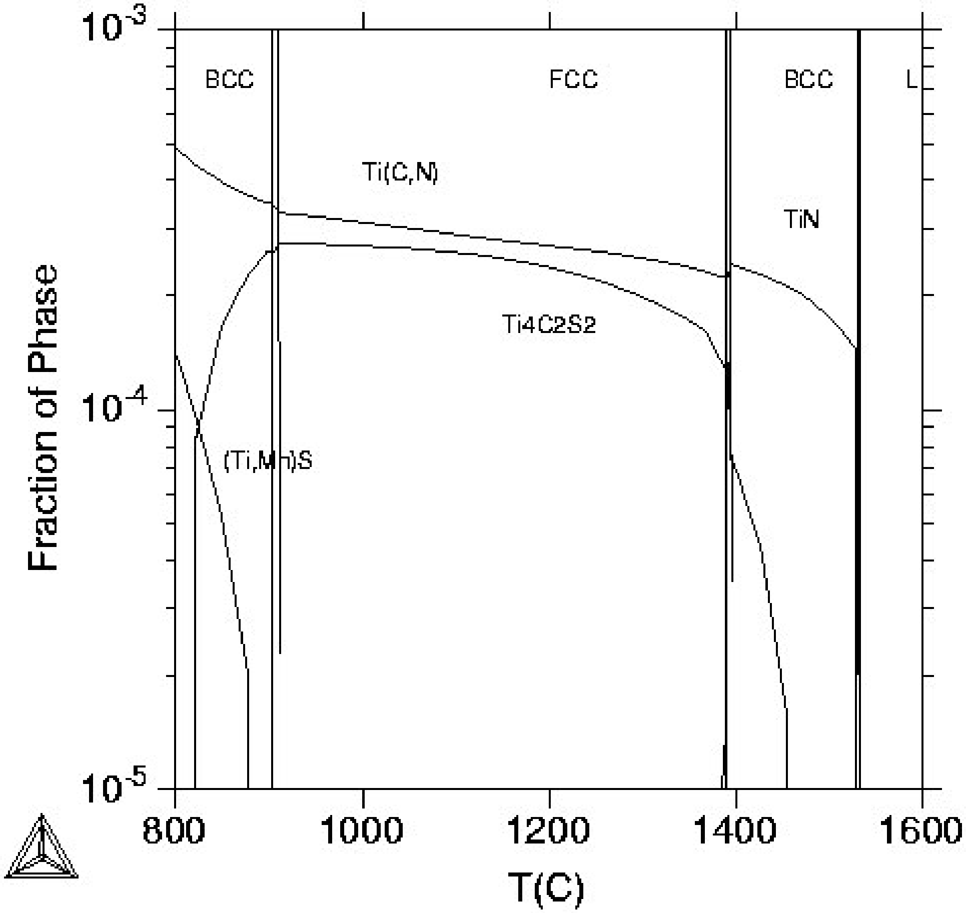


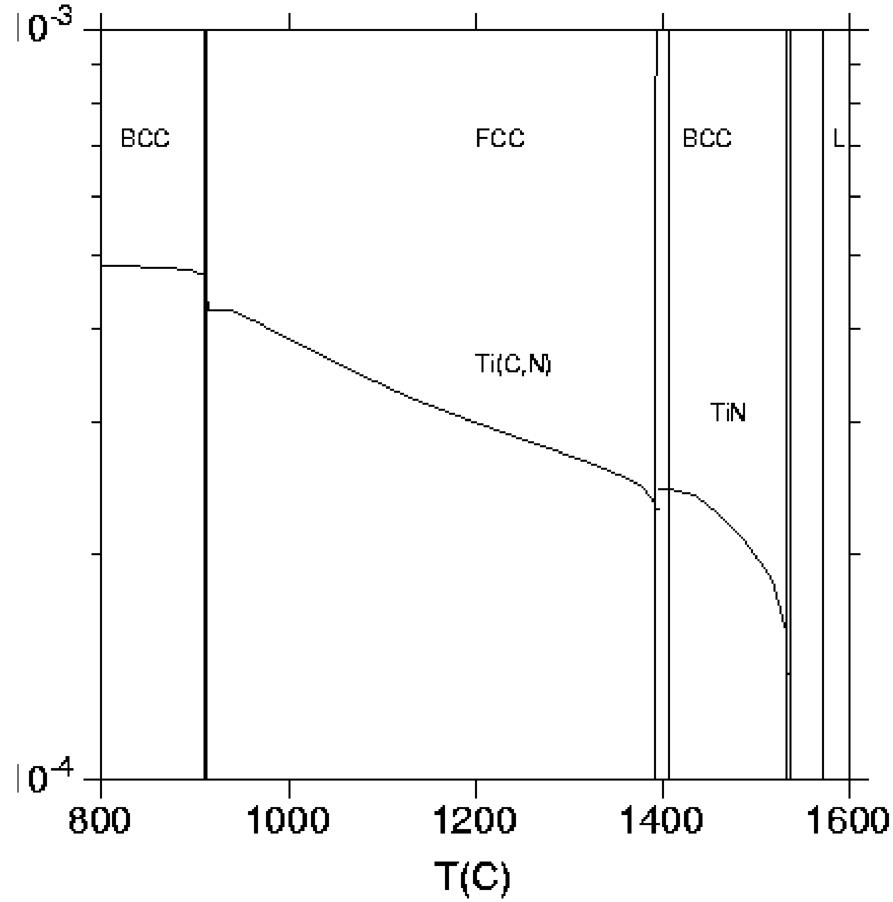
But excessive Ti causes surface defects!

Which getter? Nb?



What is the effect of S in Ti stabilized IF?





C=26ppm N=30ppm S=40ppm Ti=0.075% Mn=0.11%

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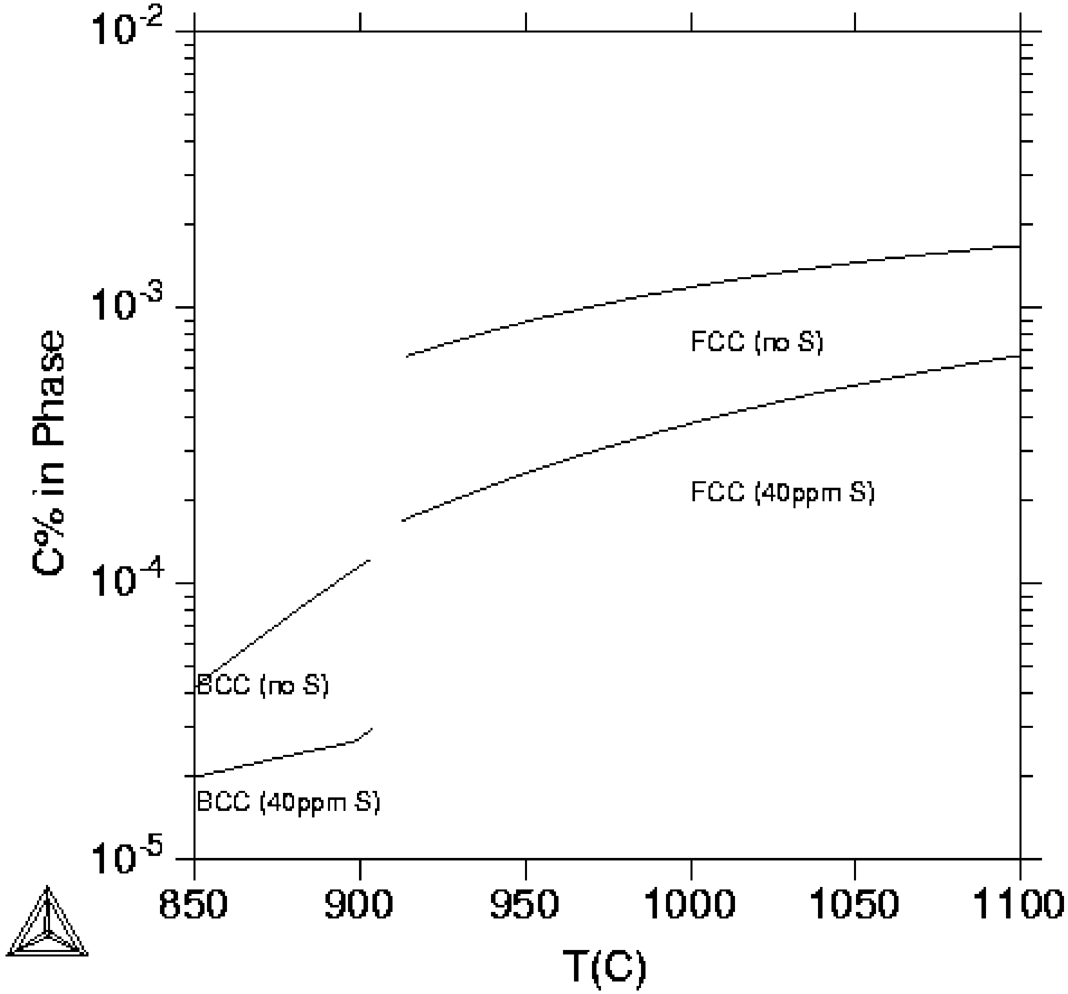
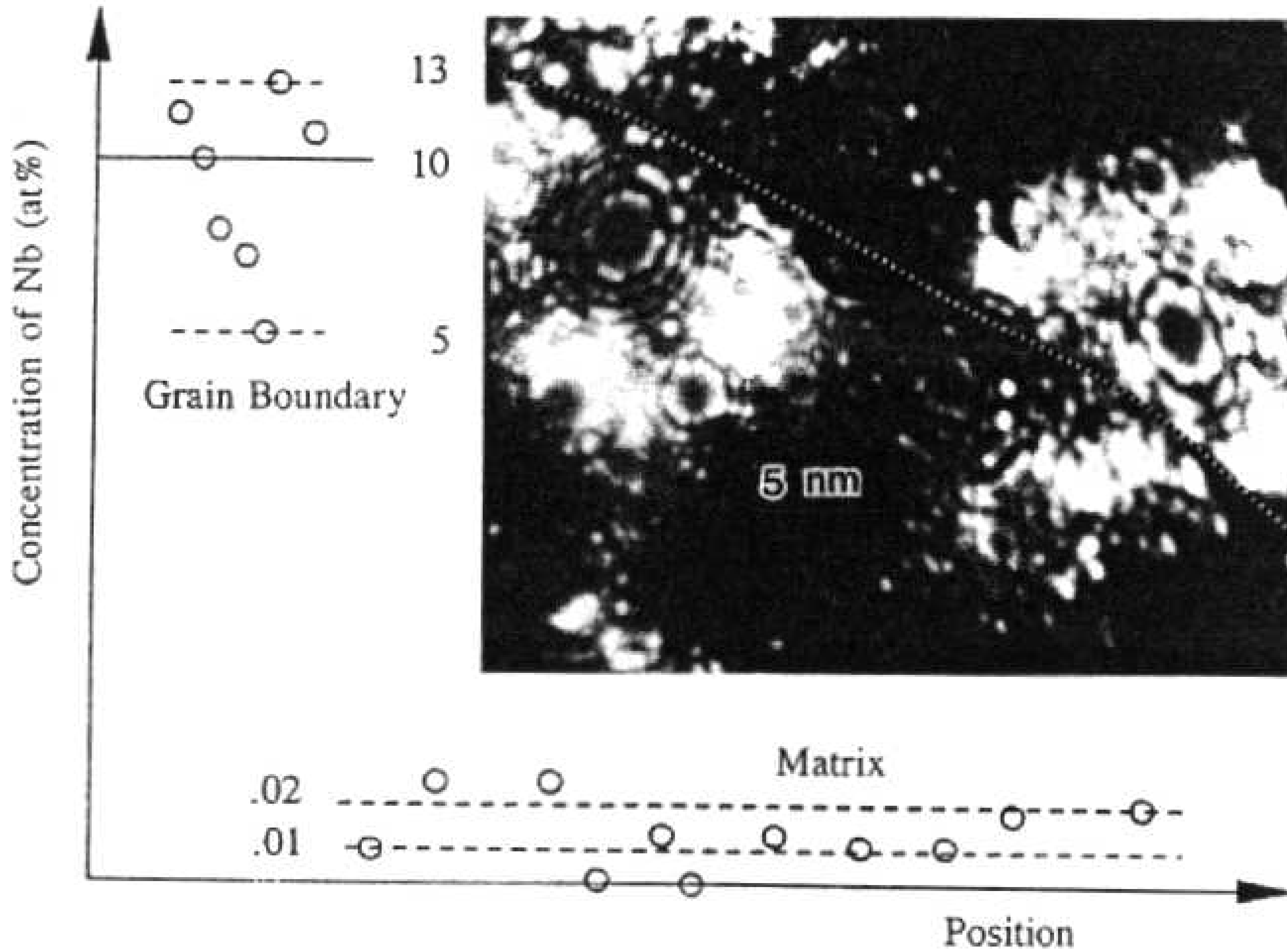
Sulfur in Ti-steel forms Ti4C2S2- Lower C in soln.



C=26ppm N=30ppm S=40ppm Ti=0.075% Mn=0.11%

Nb has positive effects in protecting grain boundaries



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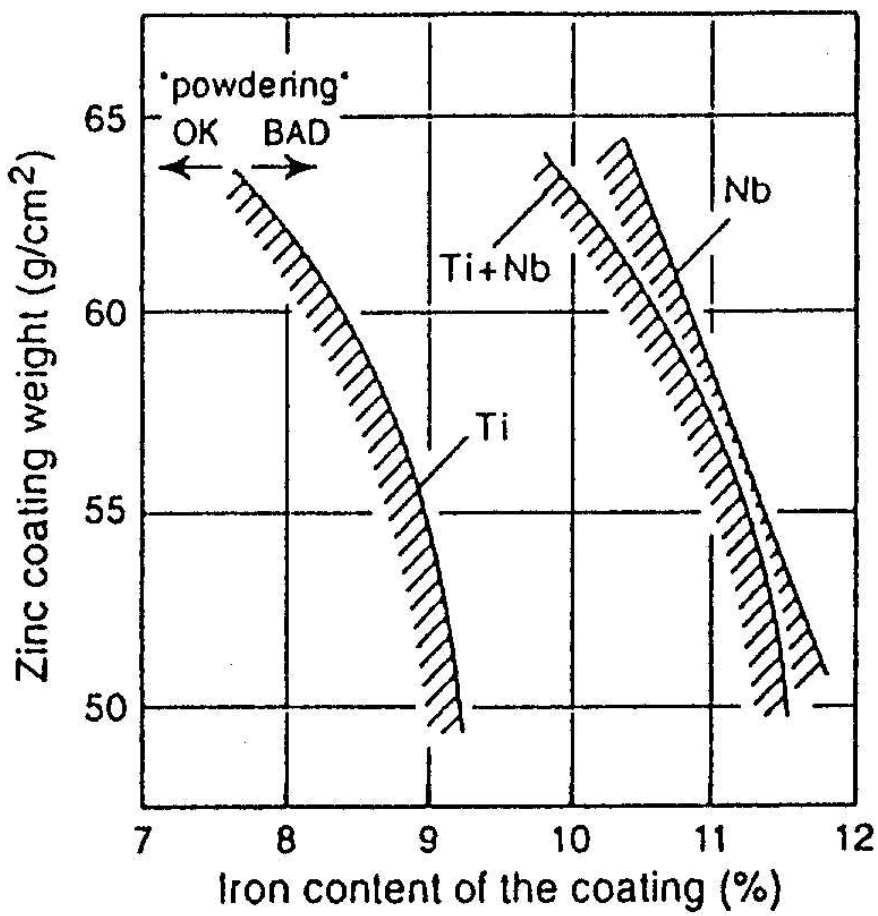
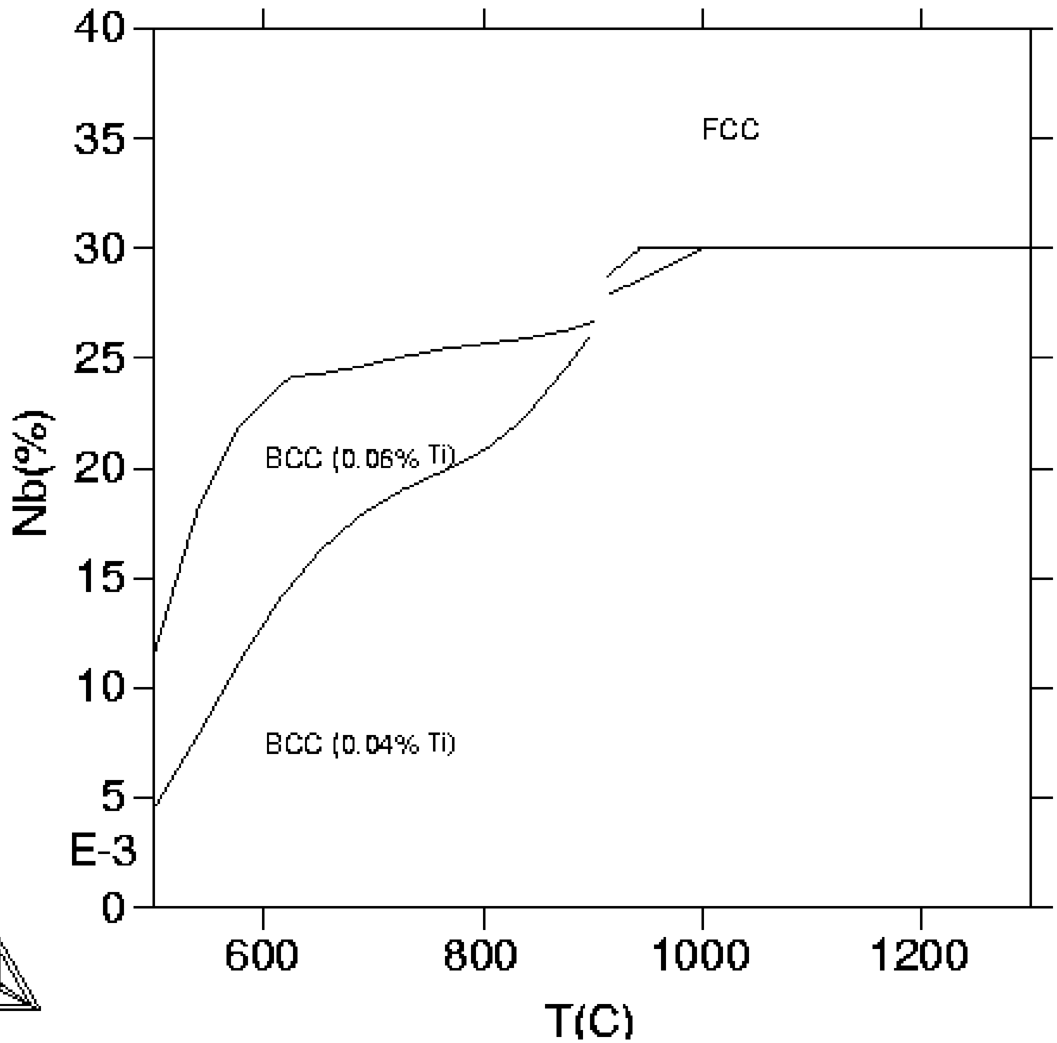
Nb in solution (in GBs) prevents powdering



Ti and Nb combination keep Nb in Solution



Adjusting Bake Hardenability

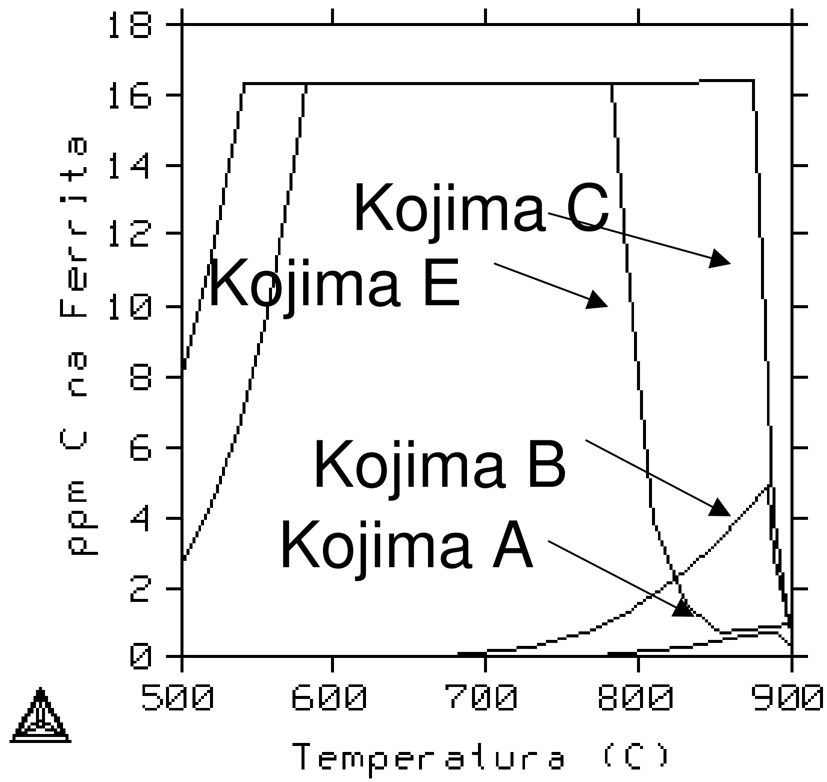
Aço	C	N	S	Ti	Nb	Mn
Kojima A	0,0020	0,0025	0,006	0,06	-	0,3
Kojima B	0,0020	0,0025	0,006	0,02	-	0,3
Kojima C	0,0020	0,0025	0,006	0,01	-	0,3
Kojima E	0,0020	0,0025	0,006	0,01	-	1,4

Kojima A:
Ti(C,N), $Ti_4C_2S_2$, (Mn,Fe,Ti)S

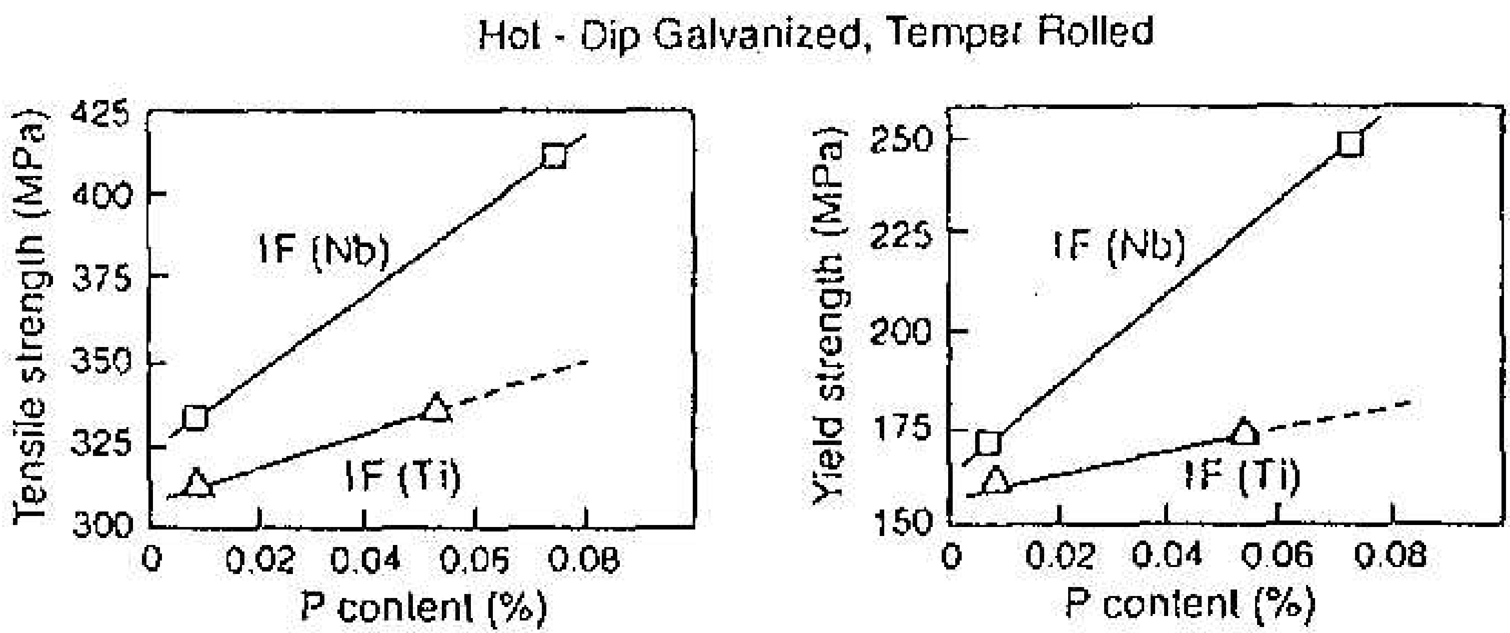
Kojima B:
Ti(C,N), (Mn,Fe,Ti)S

Kojima C:
Ti(C,N), (Mn,Fe,Ti)S,
cementite

Kojima D:
Ti(C,N), (Mn,Fe,Ti)S,
cementite



P in IF steel



Does P has other effects? Embrittlement?
Reports (TEM) that Fe-Ti-P compounds might precipitate.

FeTiP in Steel

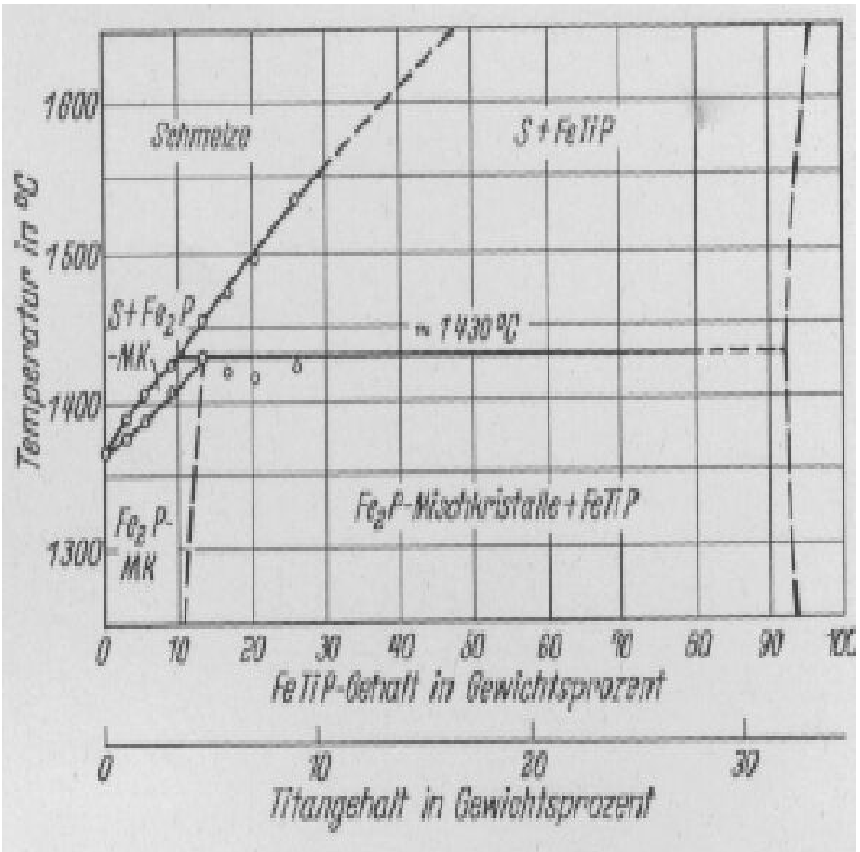
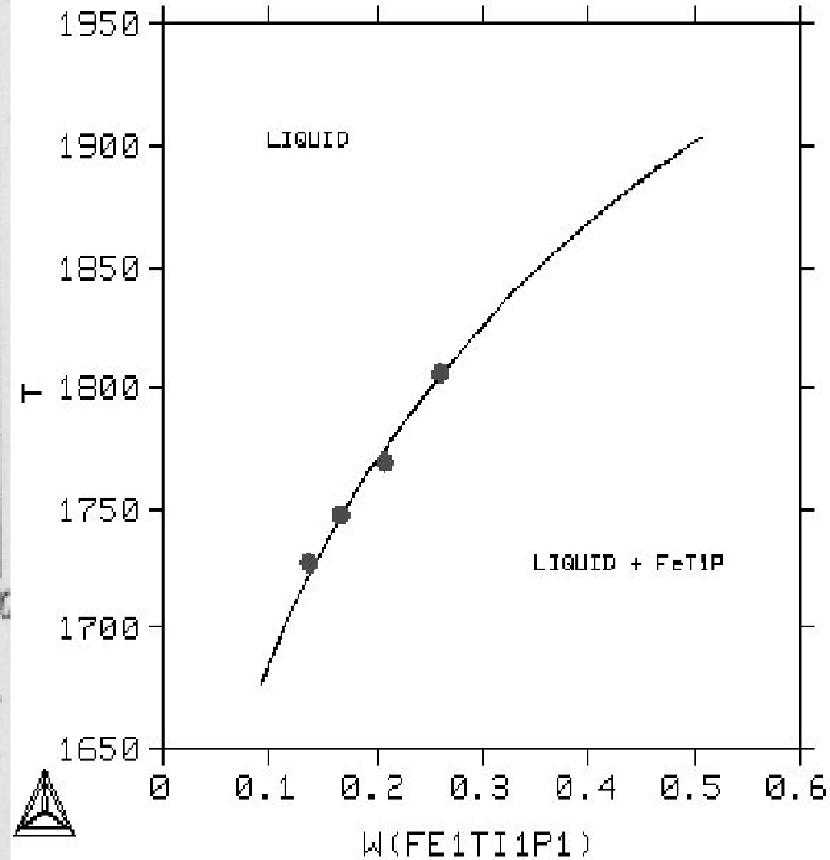


Bild 8. Schnitt I (Fe_3P—FeTiP)



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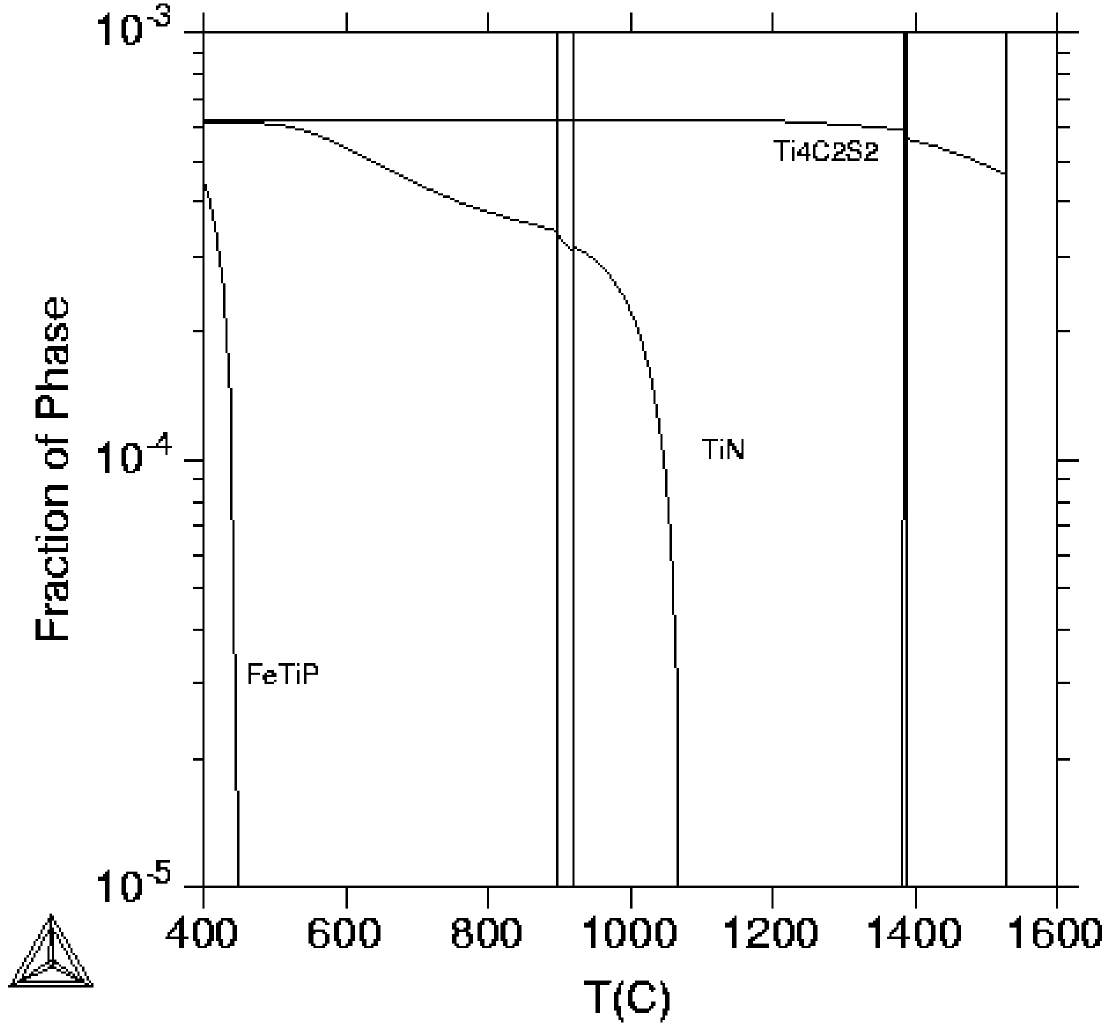
FeTiP can precipitate in Box Annealing



Conclusions

- The chemistry and processing of IF and other high formability steels is quite complex and need fine adjustment if efficiency is to be achieved.
- The control of interstitial in solution can be achieved through judicious alloy design, choosing the precipitates to be formed and their quantities.
- High formability as well as bake hardenability can be obtained this way.
- The novel range of compositions of IF steels has shown that the use of simple “solubility products” established for HSLA steels could lead to considerable error: “unexpected compounds - S and P rich can and precipitate and the CALPHAD approach can help prevent serious mistakes.
- The kinetic aspects of the processes discussed still need careful consideration for optimum alloy design.