Thermodynamic analysis of the critical condition for acicular ferrite

Peter Kolmskog, **Annika Borgenstam,**
Lars Höglund, and Mats Hillert

Materials Science and Engineering
KTH, Royal Institute of Technology

Aim

- Study if the acicular ferrite in bainite and Widmanstätten ferrite form with the same or different process.
- Study if the formation of acicular ferrite is diffusional or diffusionless without involving nucleation and growth.
- Can the wealth of information on the critical condition for formation of acicular ferrite be used to identify the governing driving force.
- Software to predict Ws, Widmanstätten start temperature, and Bs, bainite start temperature, WBs.

This study is based on thermodynamic facts and not on transformational mechanisms and include C, Cr, Mn, Mo and Si.

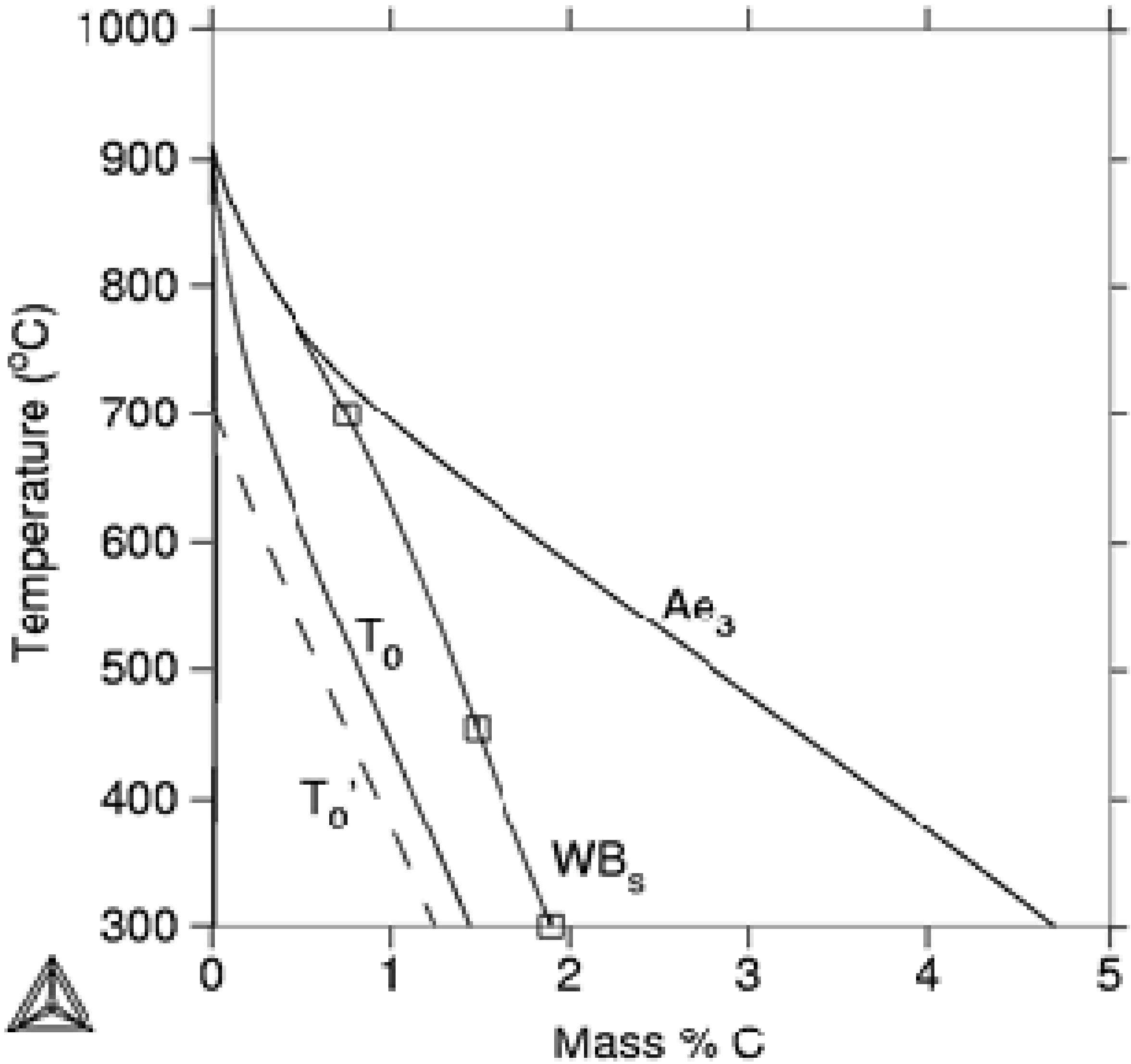
Critical condition for formation of acicular ferrite

Controlled by some barrier that requires a driving force to be surmounted.

T_0'-Diffusionless

WB_s-Diffusional

Hillert et al 2004



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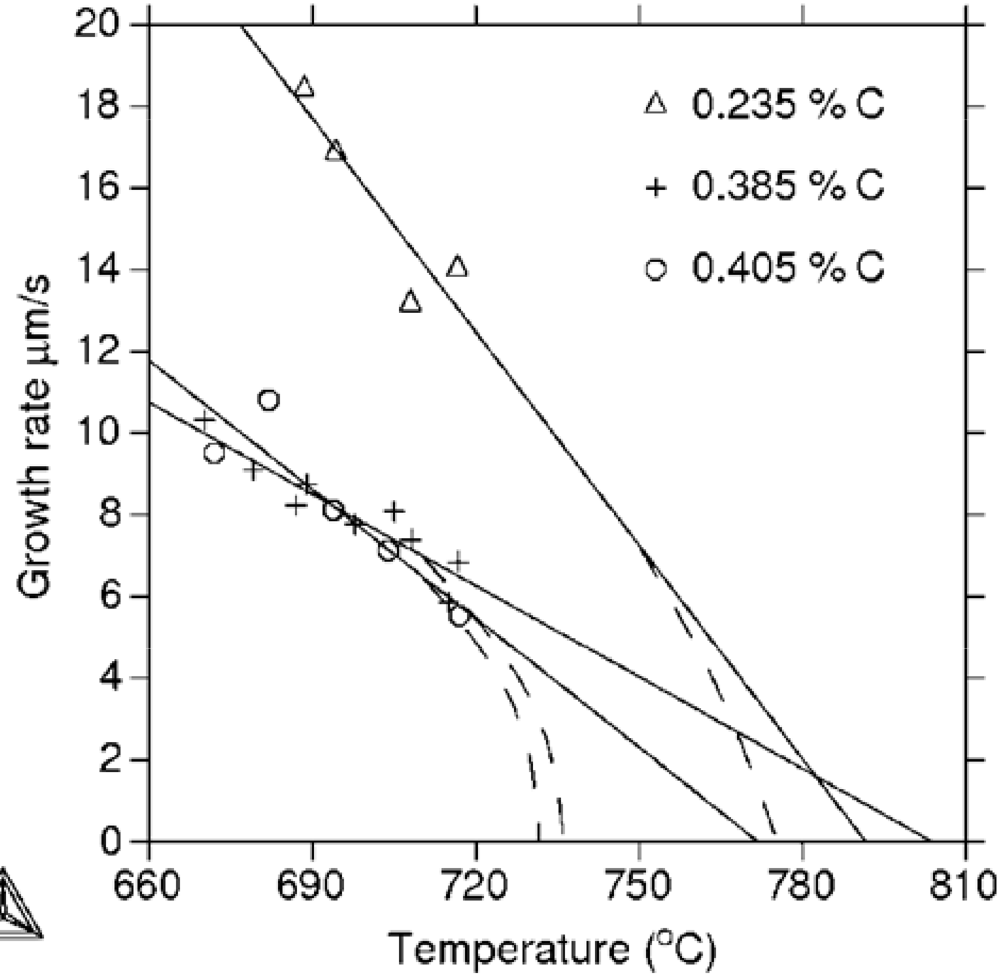
Experimental information on critical temperature at a fixed composition of the austenite

First appearance of acicular ferrite.

- By direct observation
- By extrapolation, e.g volume fraction lengthening rates
- From old TTT diagrams
- From more recent TTT diagrams
- Using continuous cooling

By extrapolation of the growth rate to get the critical temperature

- Experimental values from Townsend and Kirkaldy, 1968

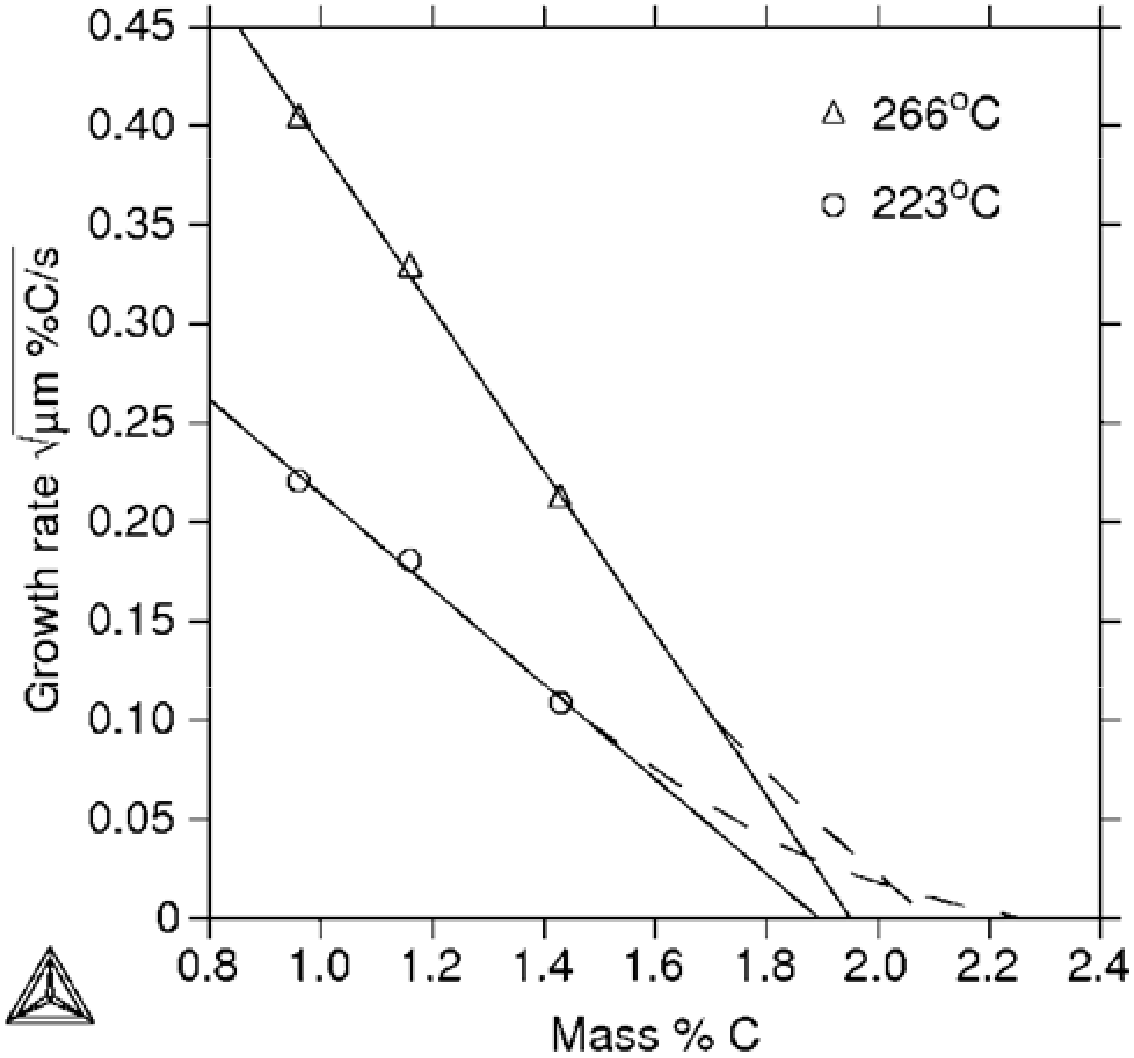


Experimental information on critical carbon content of the austenite at a certain temperature

- By extrapolation, growth rates
- From volume fraction on the plateau
- From retained austenite using XRD
- From atom probe tomography
- From the local carbon content where growth stops

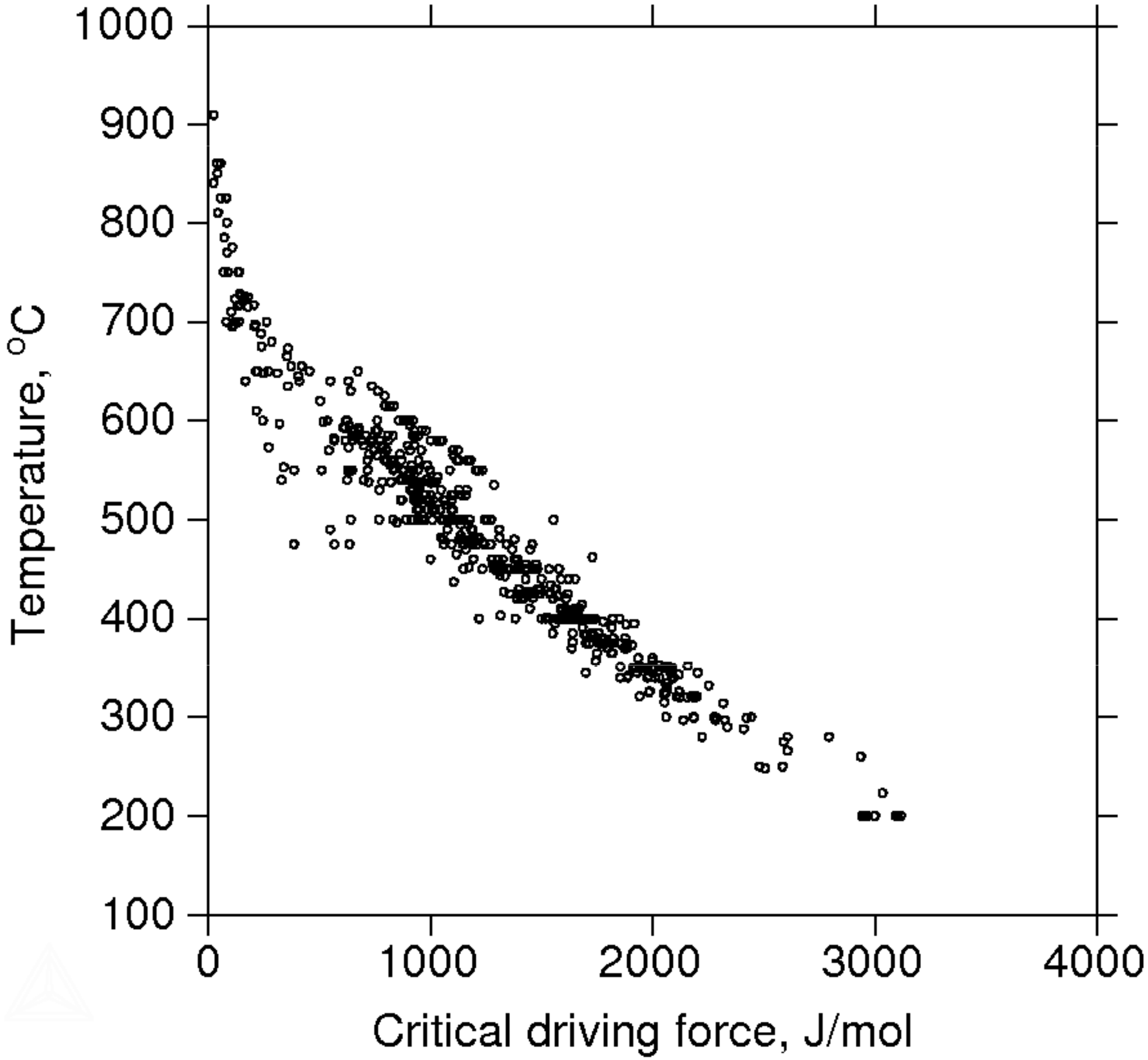
By extrapolation of the growth rate to get the critical carbon content

- Experimental values from Speich and Cohen, 1960



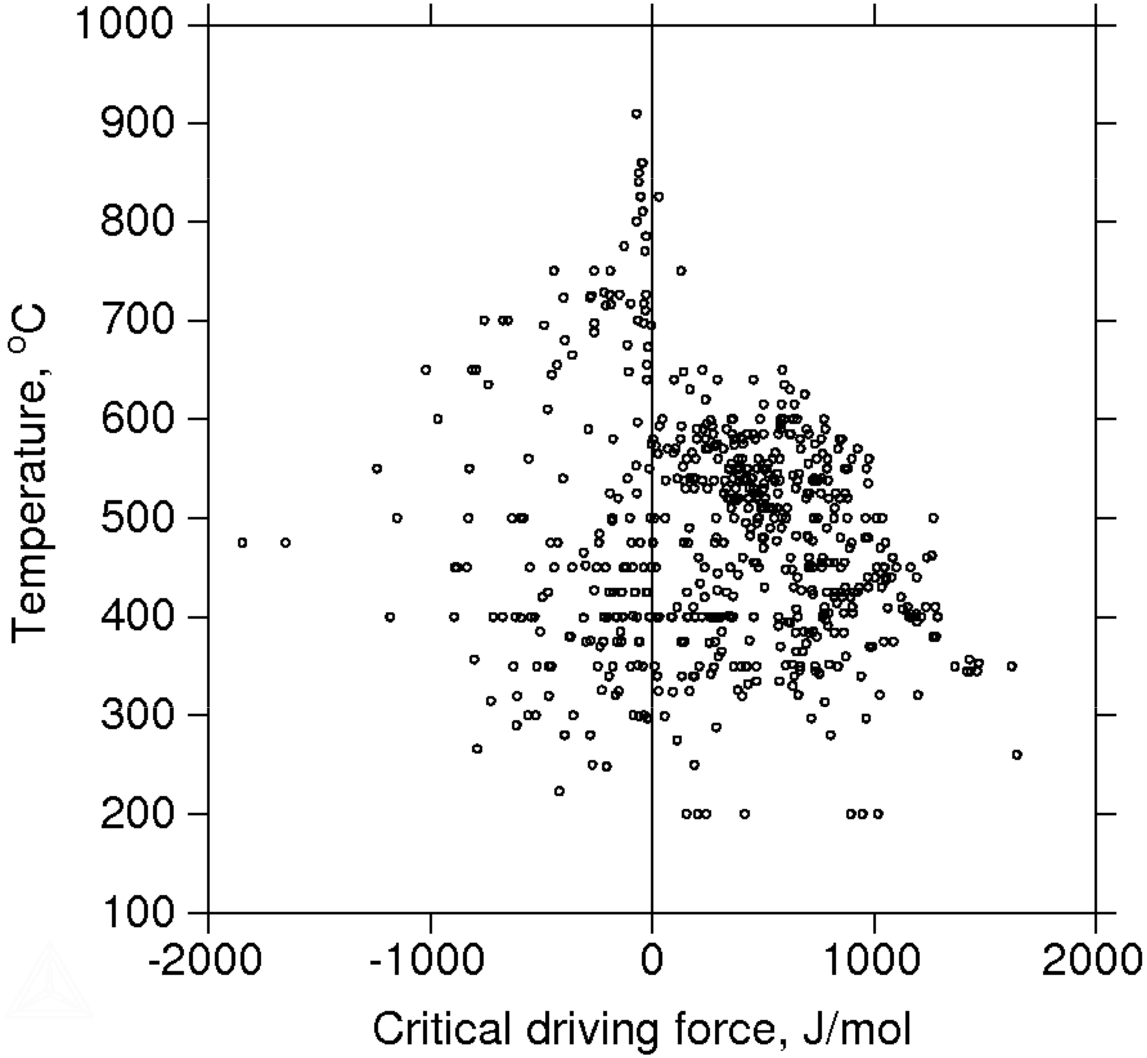
Critical driving force for a diffusional transformation

- 594 Fe alloys
- Evaluated from critical condition for formation av acicular ferrite
- Paraequilibrium



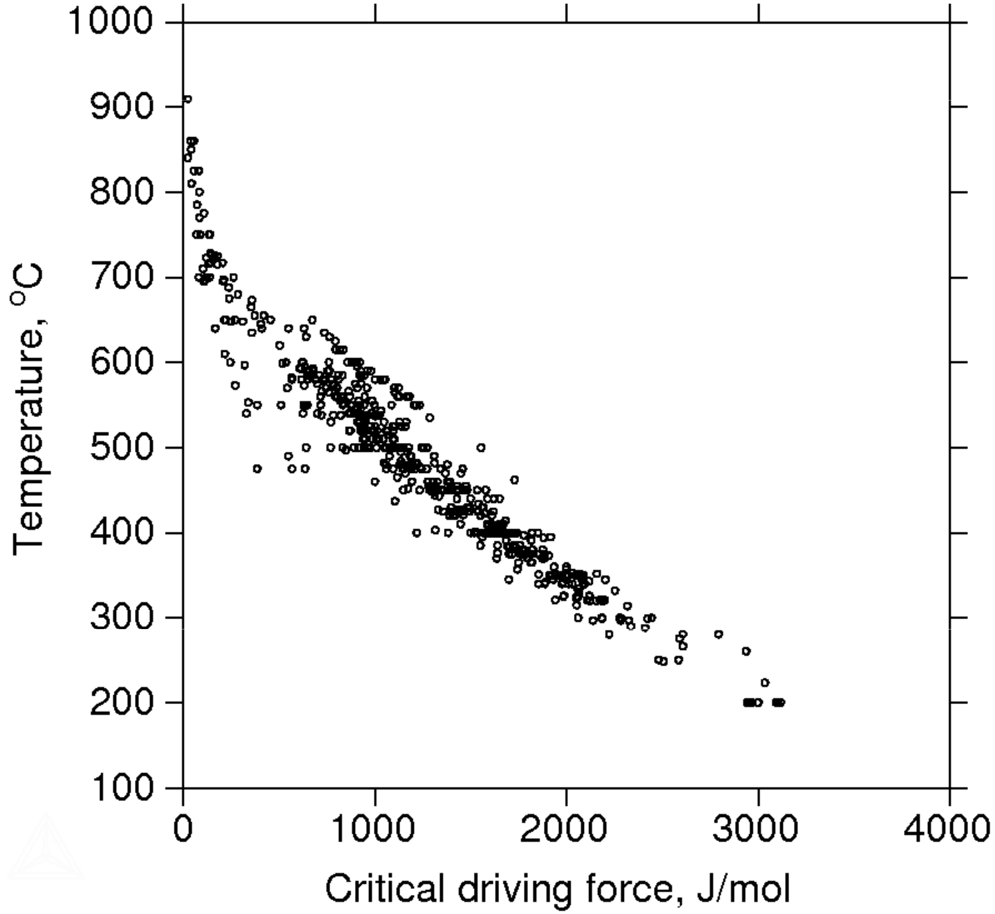
Driving force for a diffusionless transformation

- 594 Fe alloys
- Evaluated from critical condition for formation av acicular ferrite

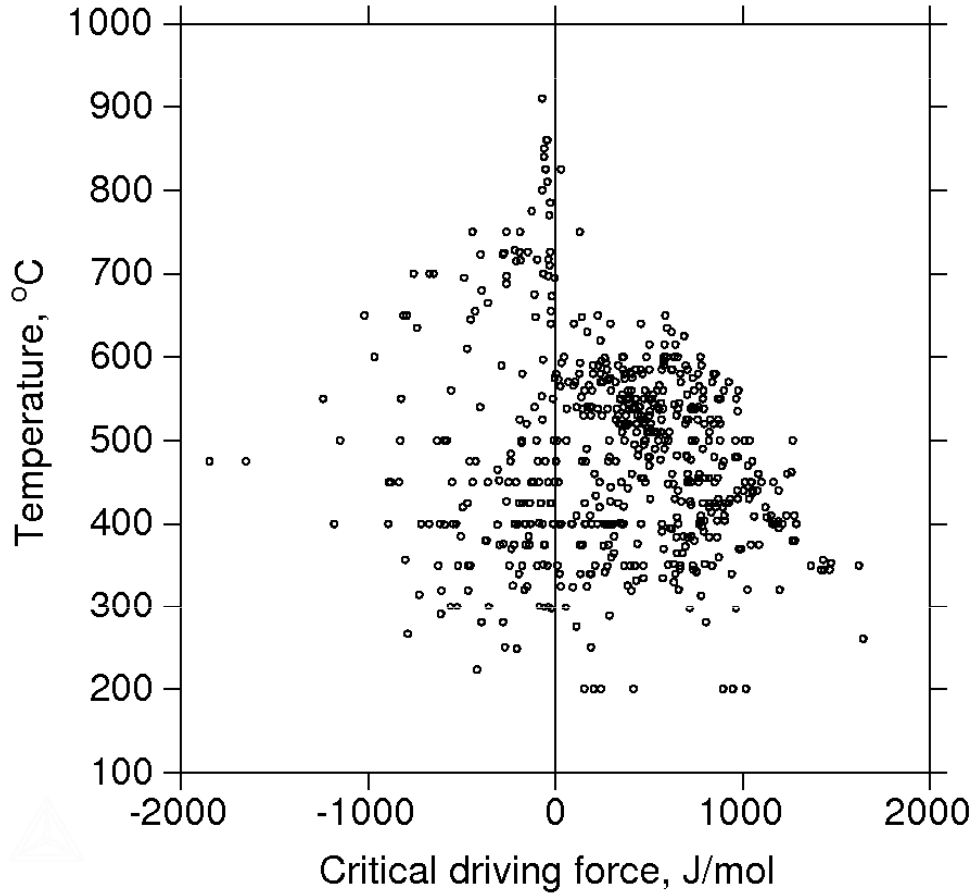


Comparison between critical driving force

Diffusional

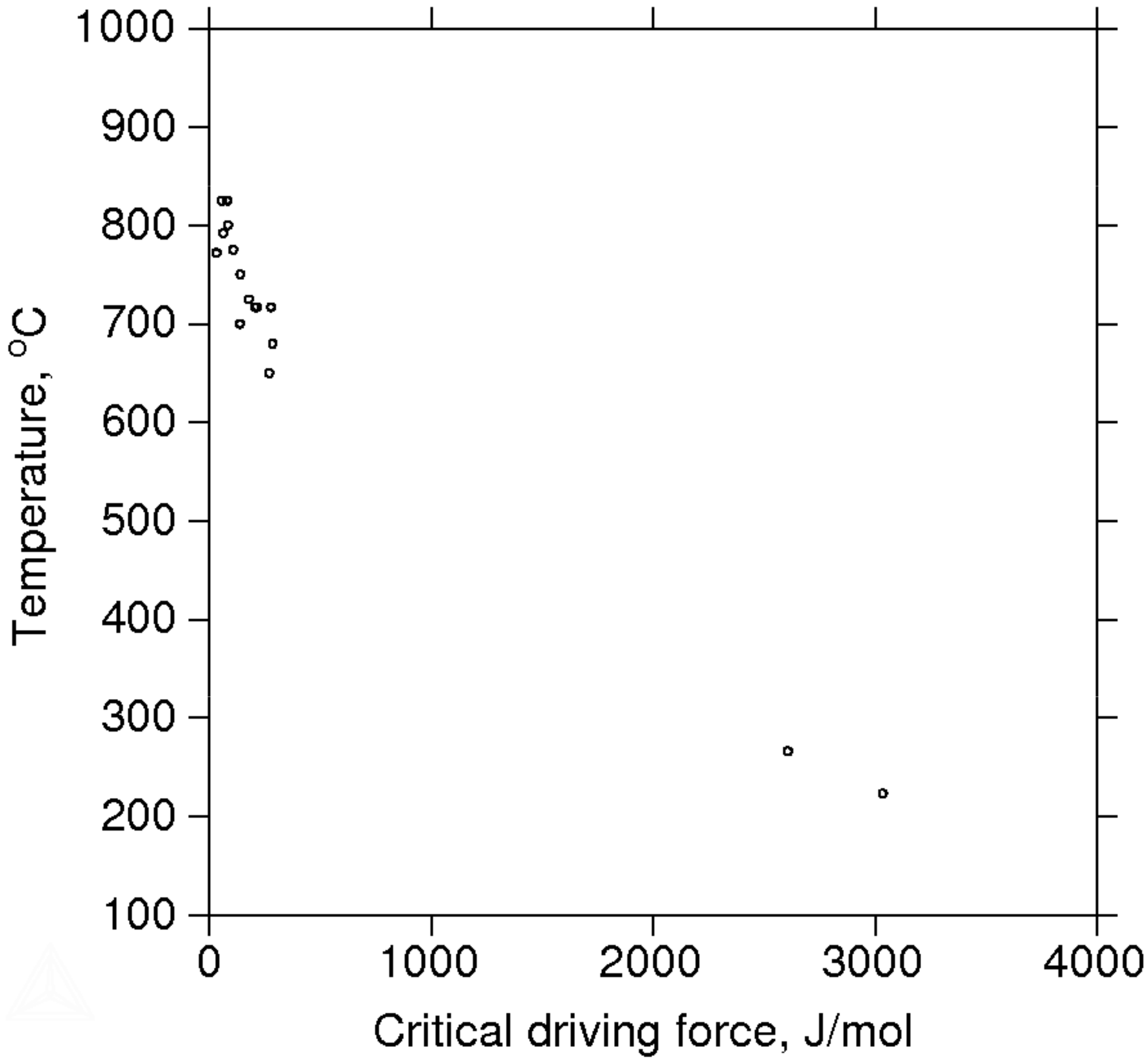


Diffusionless



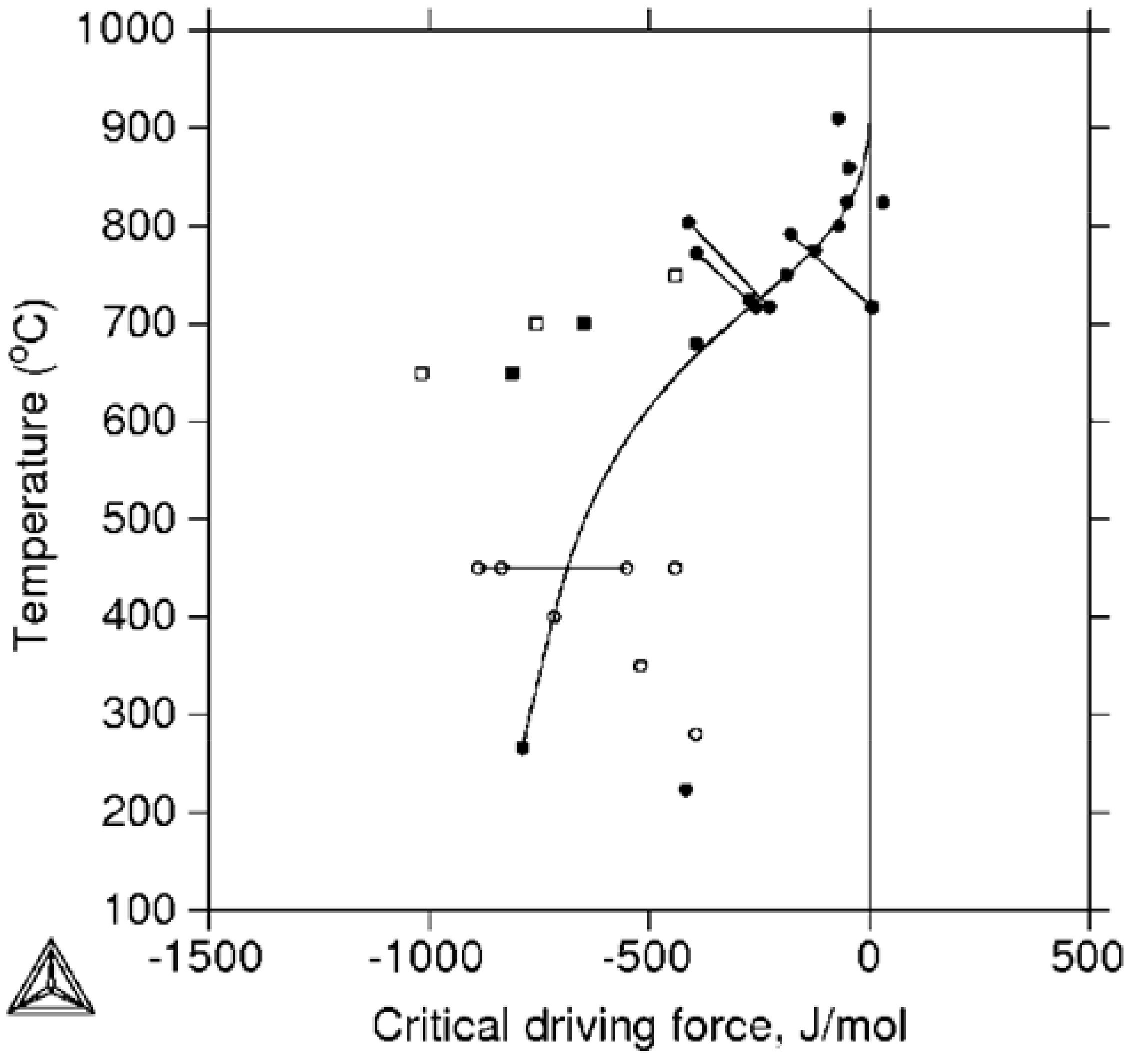
Driving force for a diffusional process

- Evaluated from critical condition for formation of acicular ferrite in Fe-C



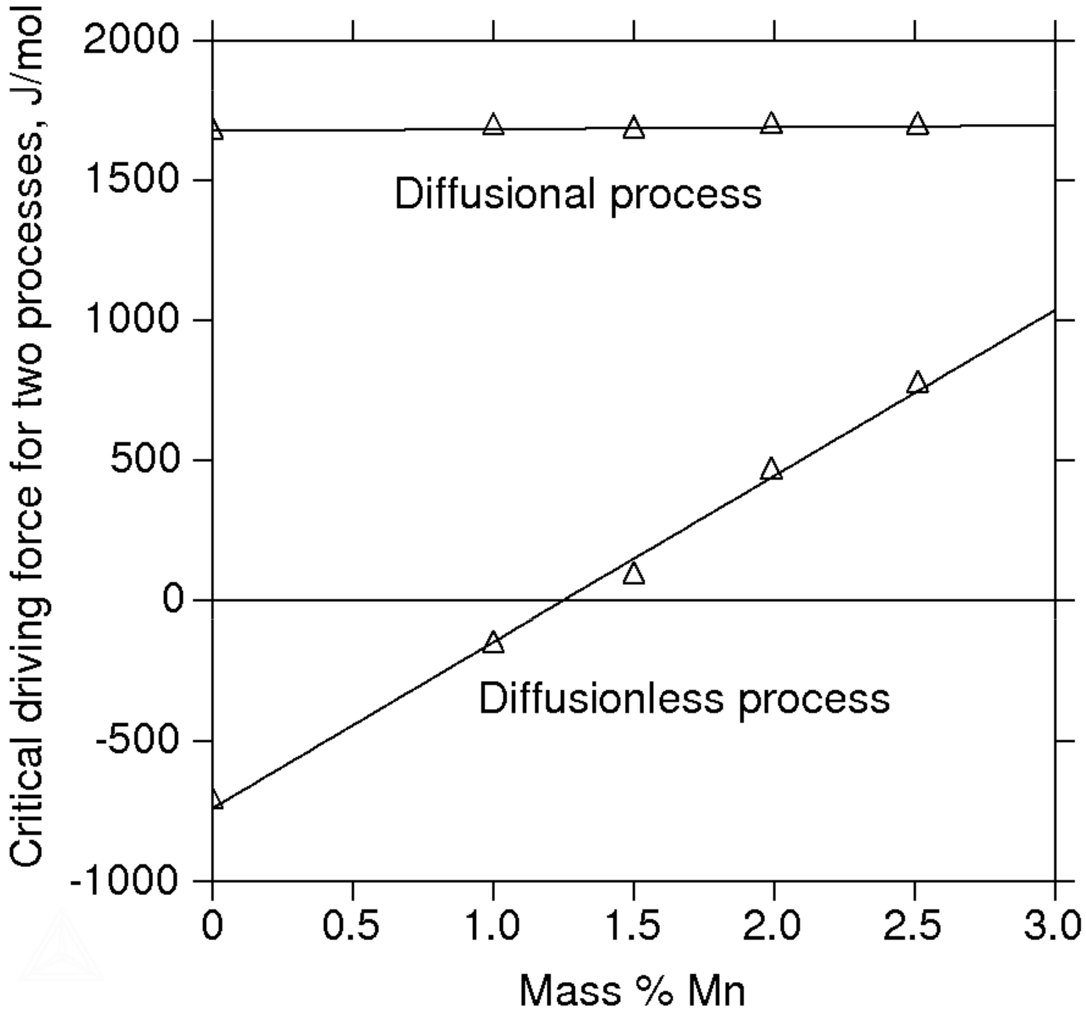
Driving force for a diffusionless process

- Evaluated from critical condition for formation av acicular ferrite Fe-C and Fe-C-Si.
- Si was assumed to have a negligible effect on critical driving force.



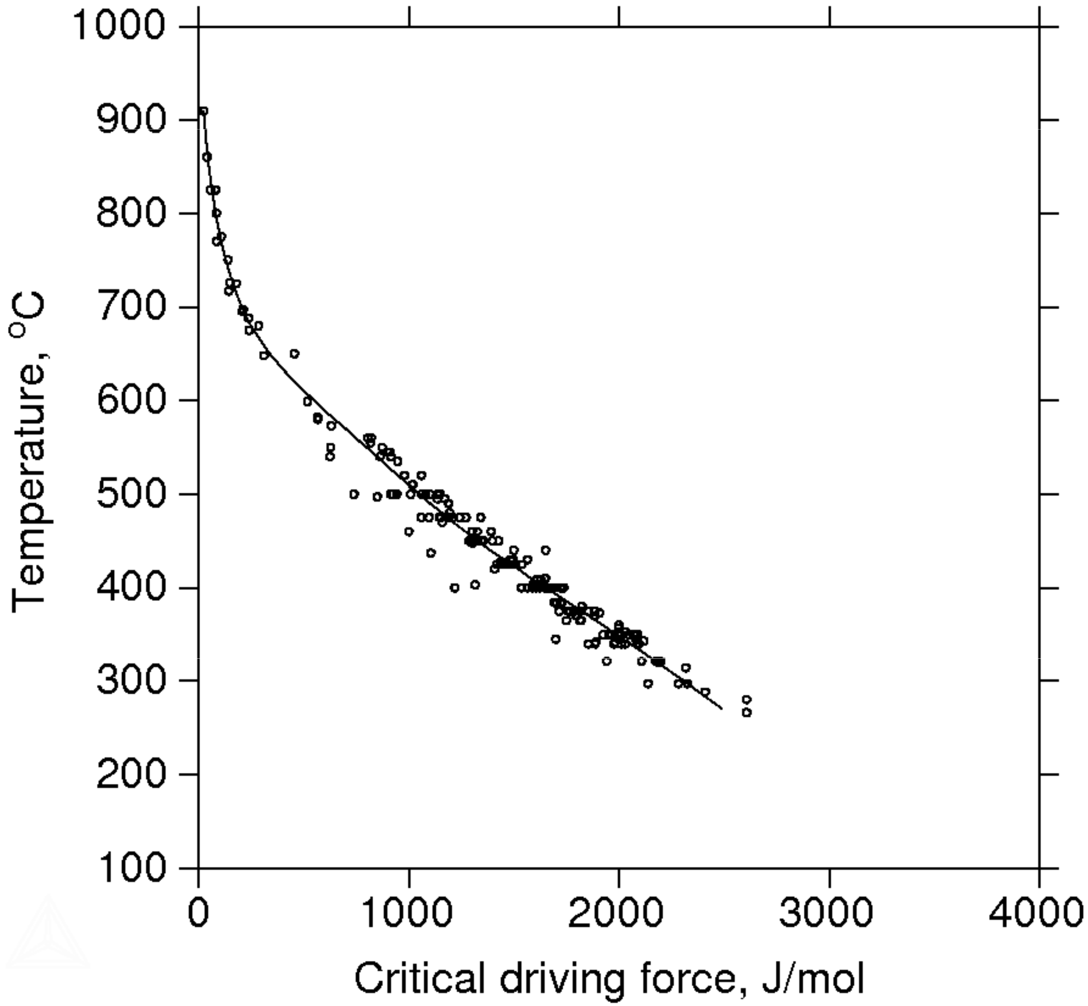
Critical driving force for diffusional and diffusionless process at 673 K

Fe-C-Mn-1.5 mass%Si



Driving force for a diffusional process

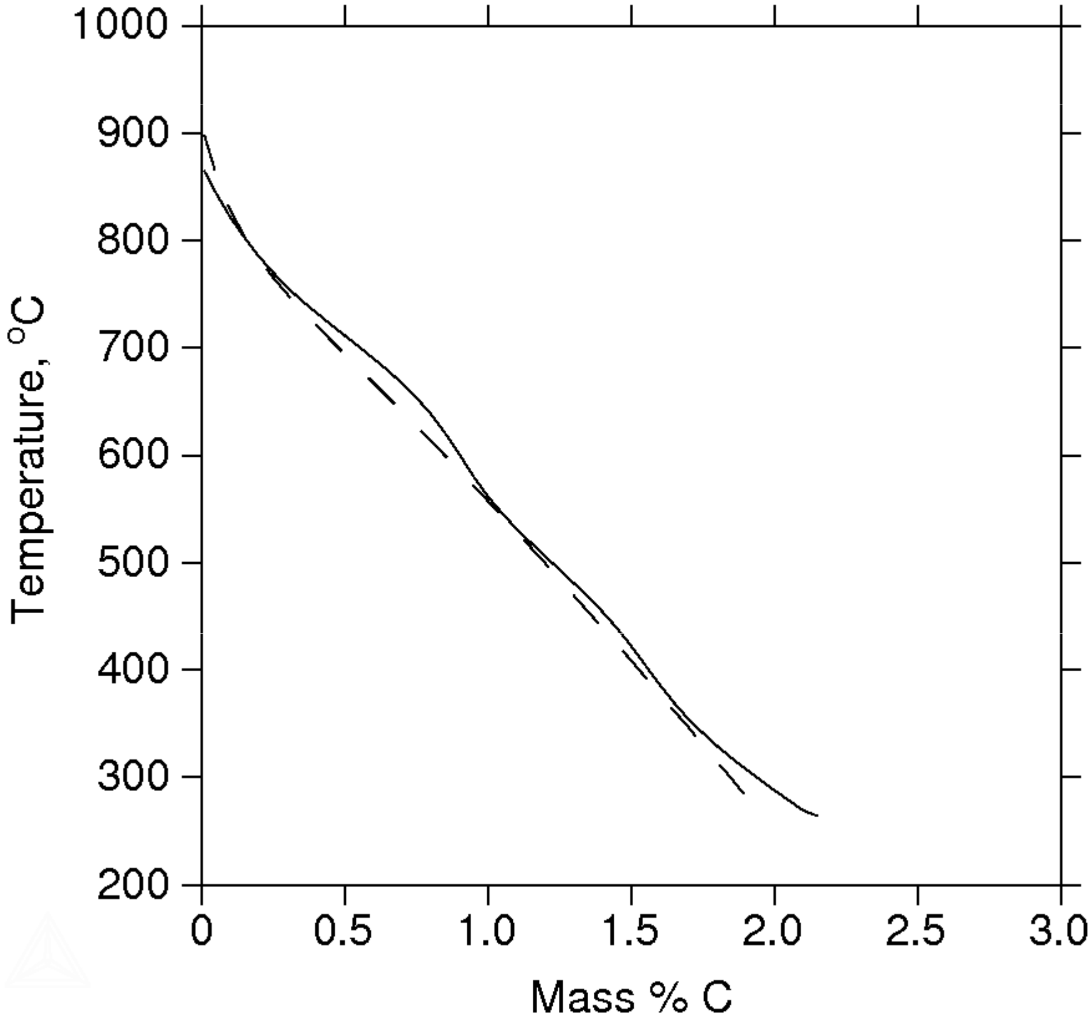
- Evaluated from critical condition for formation av acicular ferrite Fe-C, Fe-C-Si and Fe-C-Si-Mn



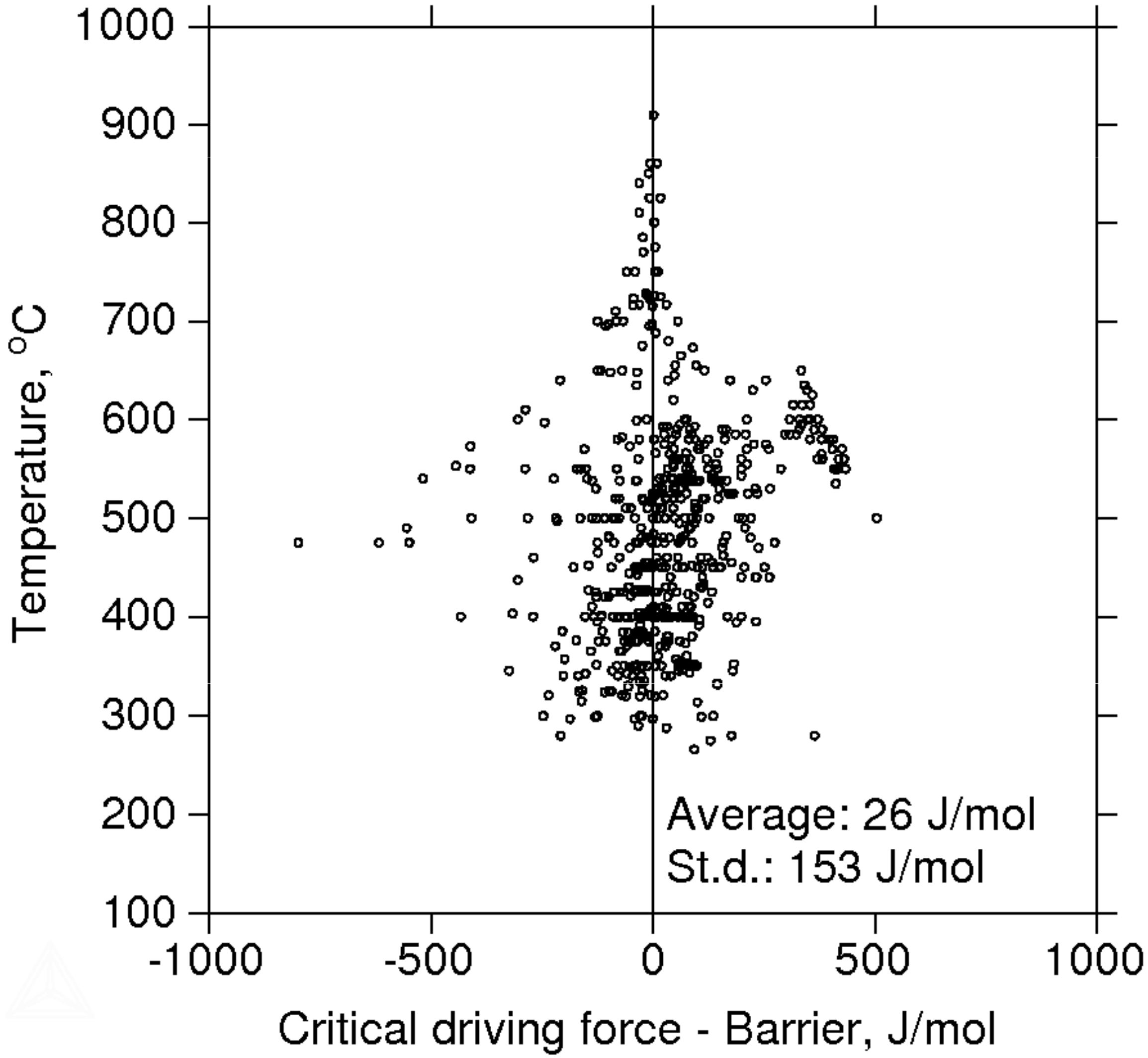
Comparison of critical carbon contents for acicular ferrite for a diffusional and a diffusionless process

Full line - Diffusional

Dashed line - Diffusionless

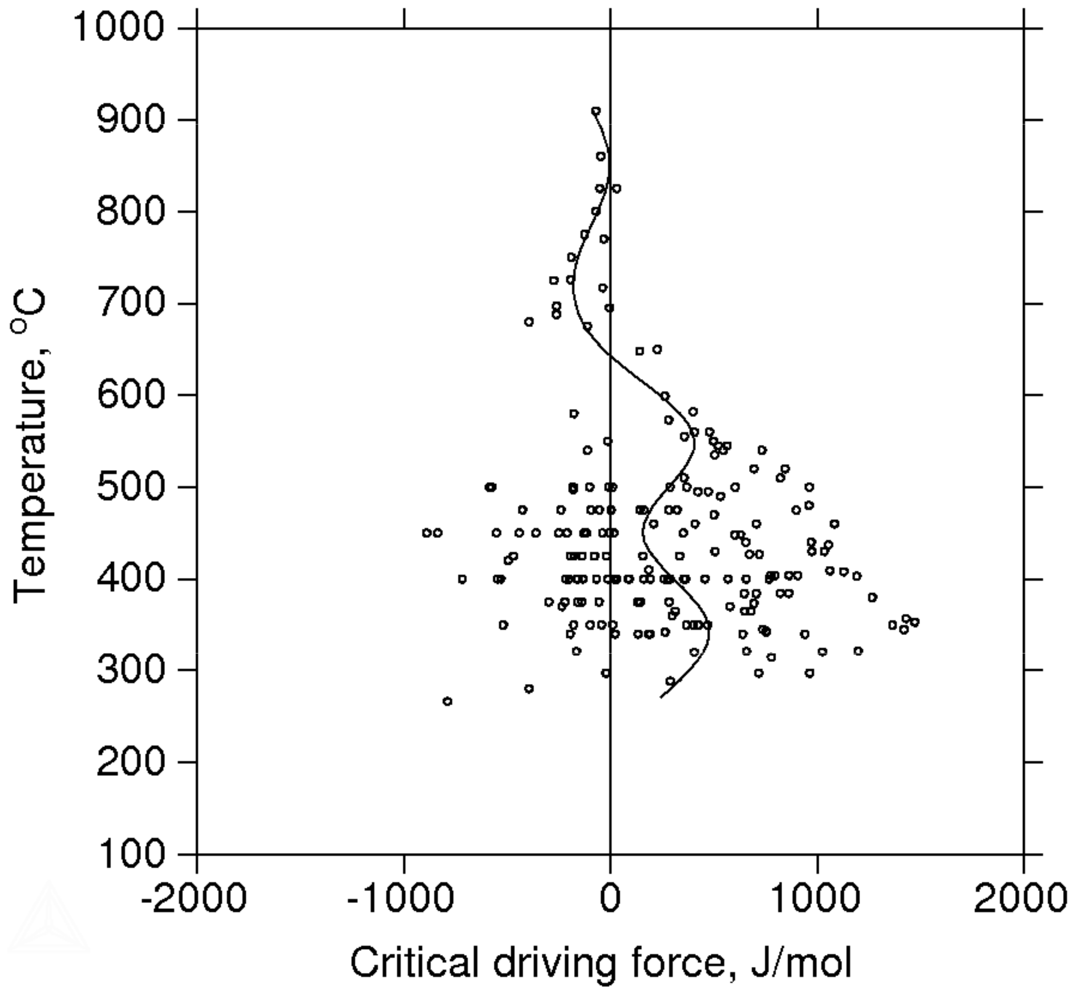


Difference between critical driving force and the barrier for a diffusional process

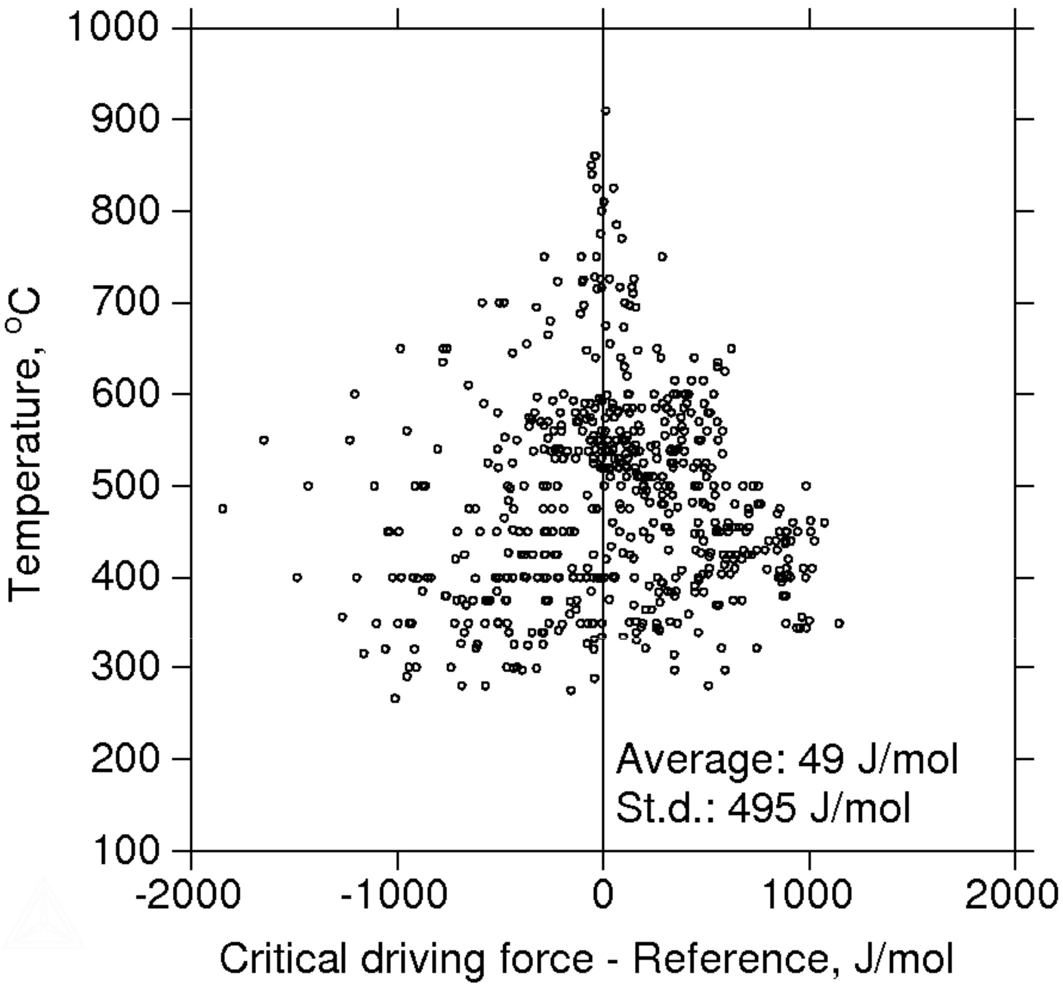


Reference for a diffusionless process

- Evaluated from critical condition for formation av acicular ferrite Fe-C, Fe-C-Si and Fe-C-Si-Mn

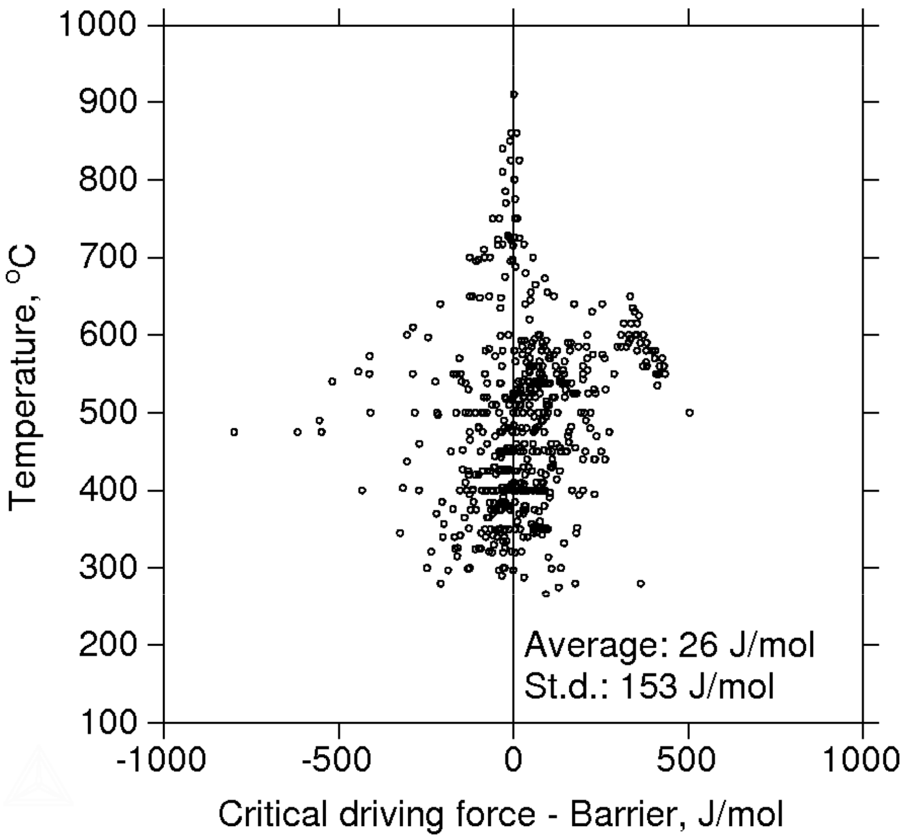


Difference between critical driving force and the reference for a diffusionless process

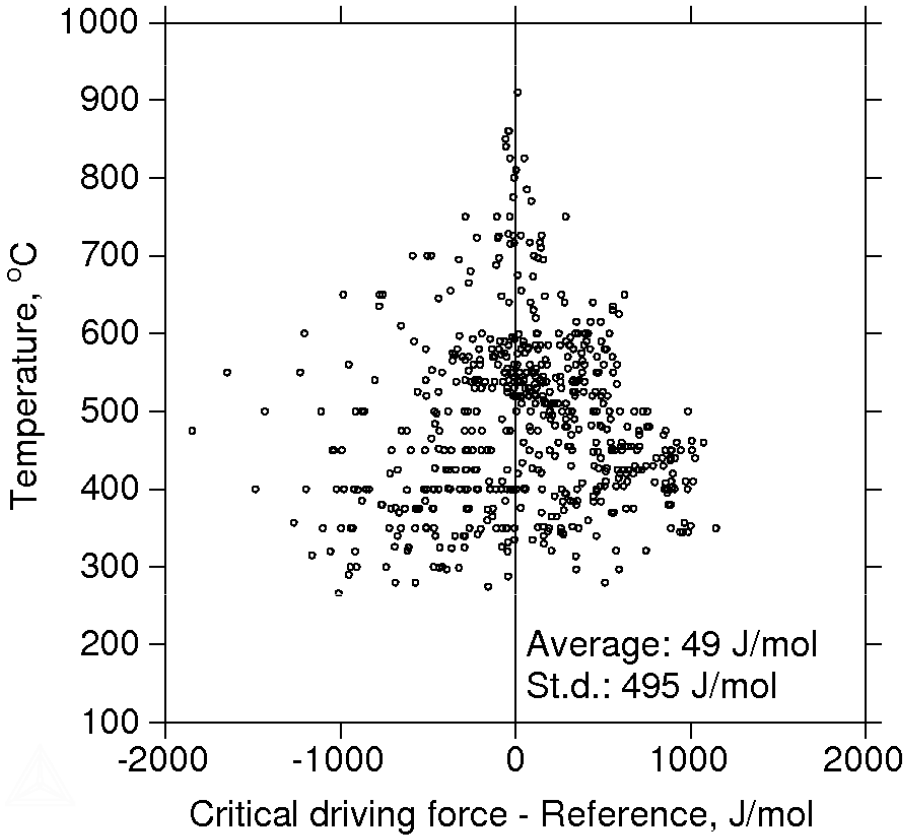


Comparison between difference between critical driving force and barrier/reference

Diffusional



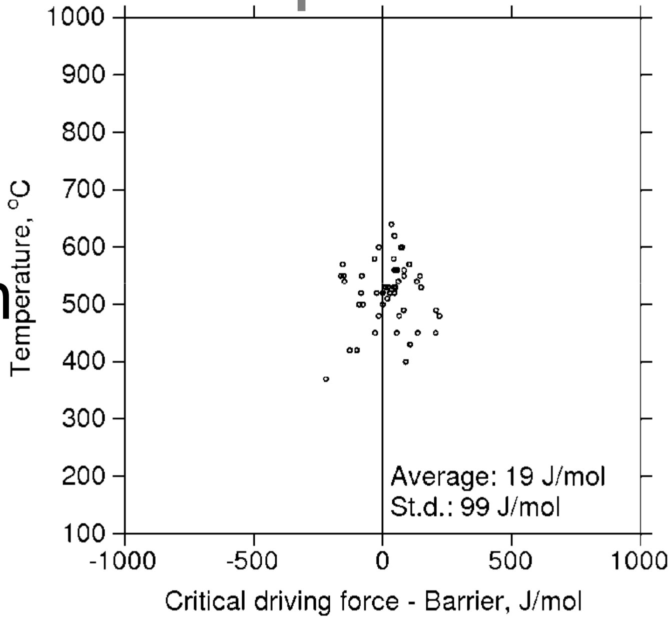
Diffusionless



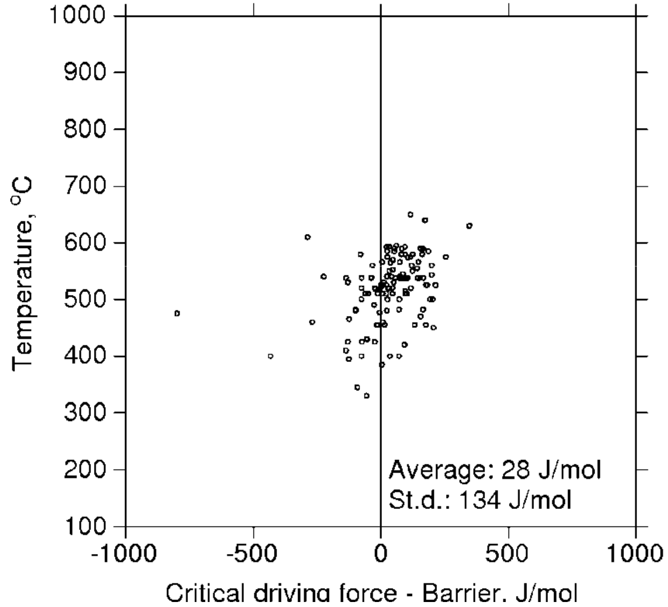
Observe the difference in x-scales!!!!!!

Comparison of different measuring techniques for a diffusional process

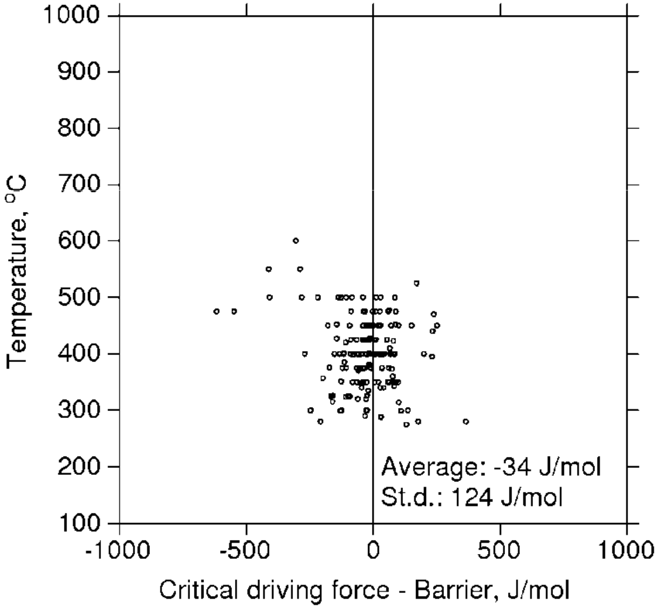
Extrapolation



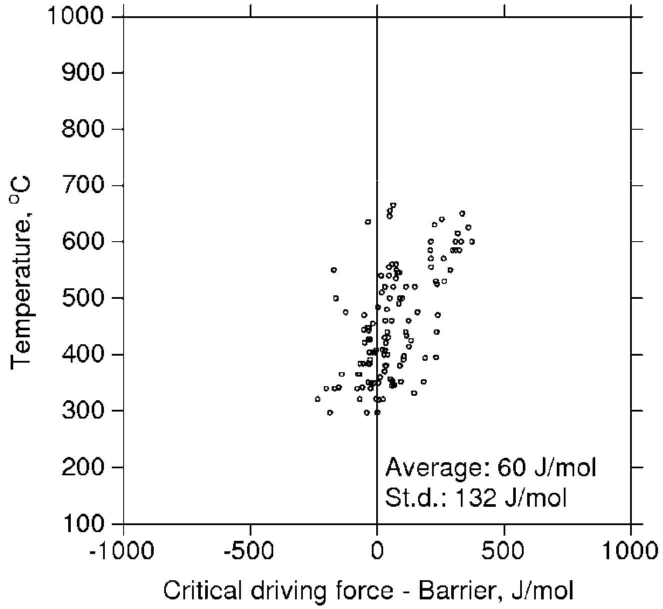
Old TTT diagrams



Retained austenite using XRD

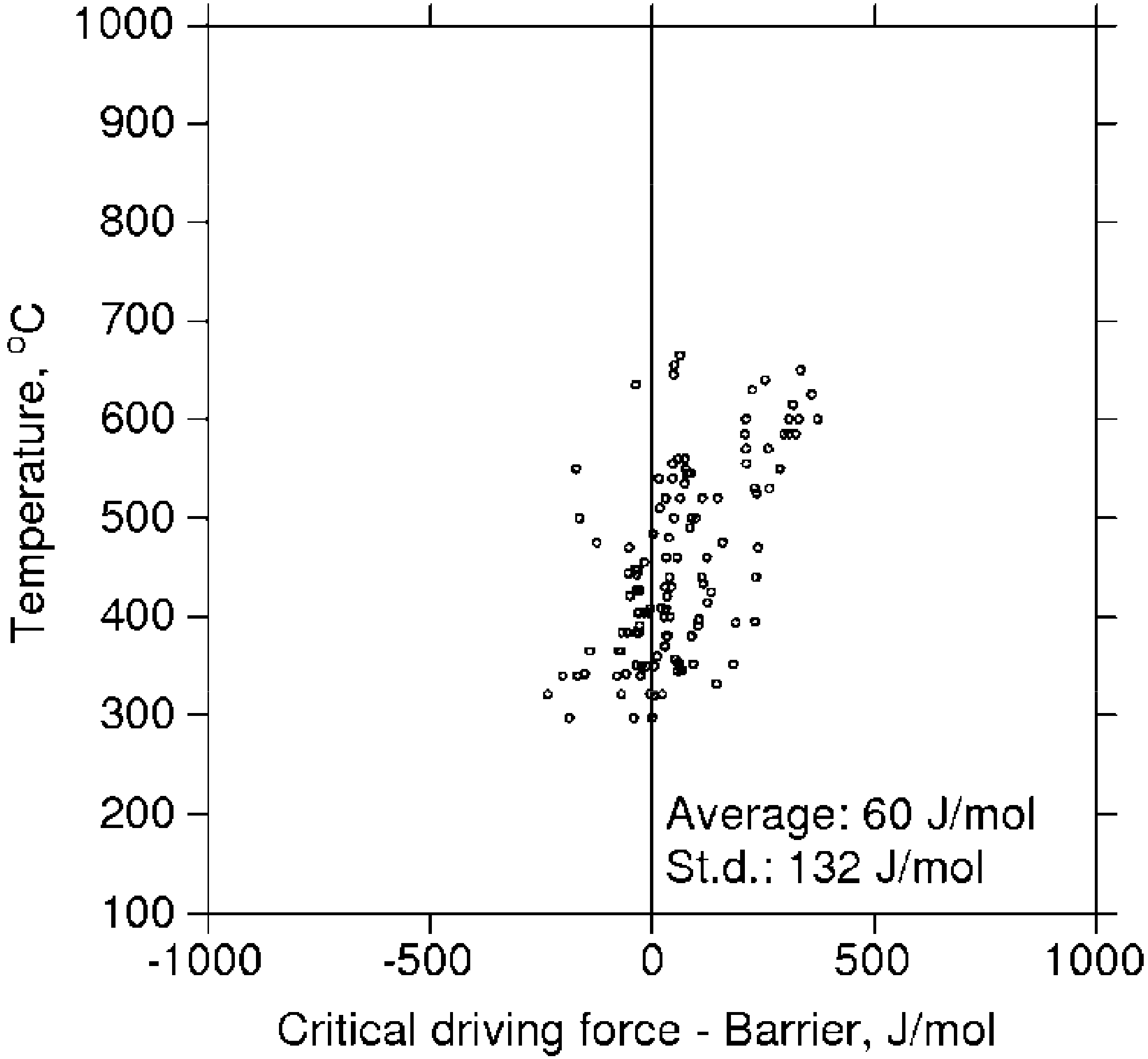


Volume fraction on the plateau

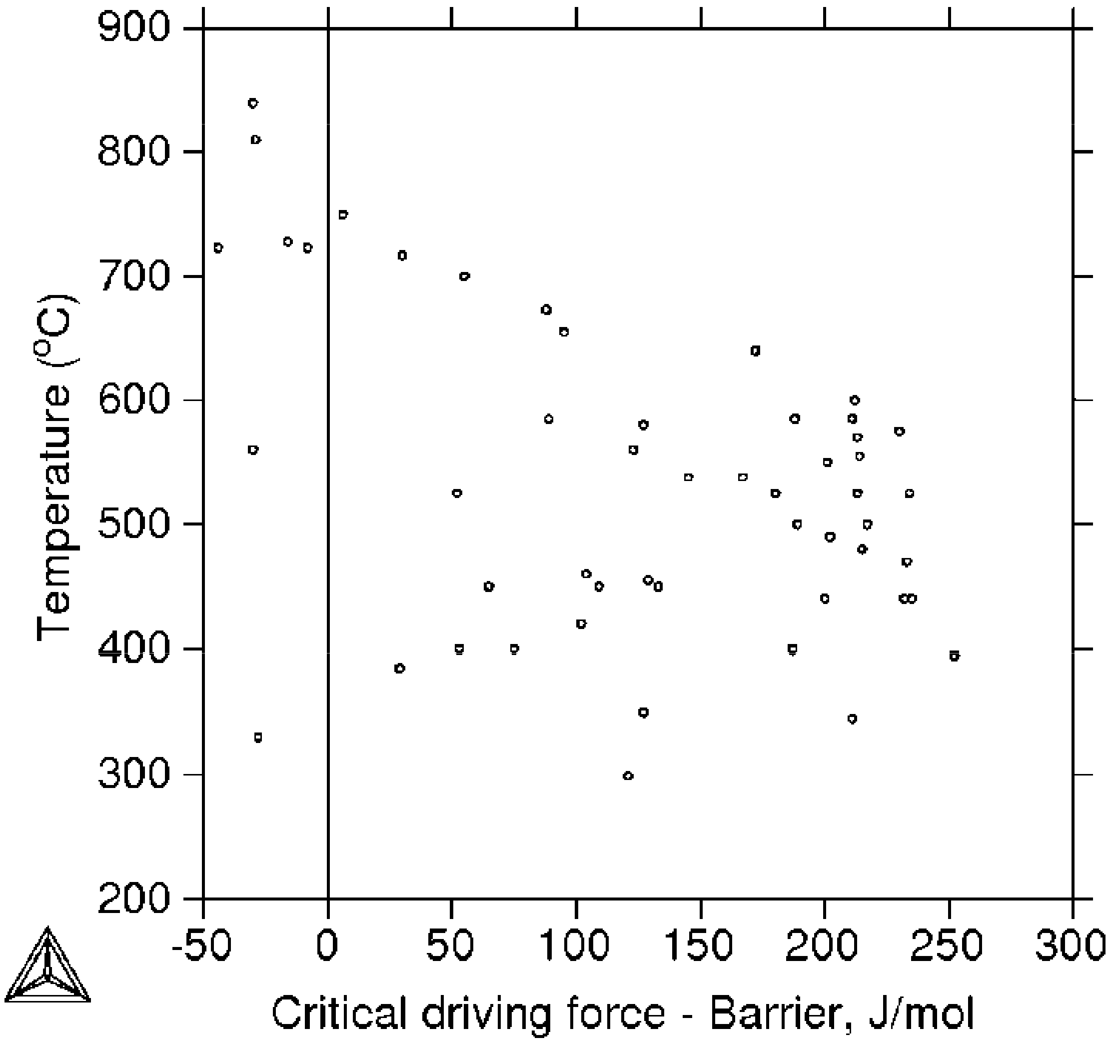


Comparison of different measuring techniques for a diffusional process

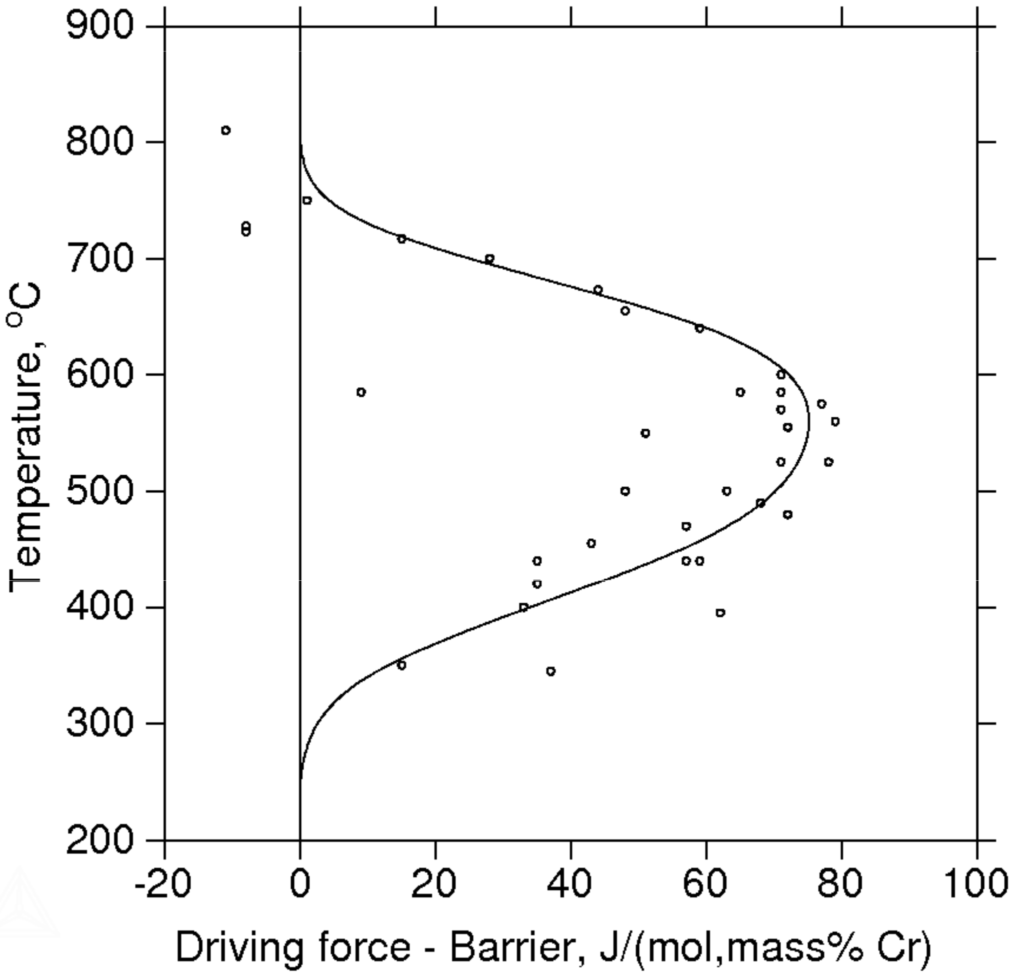
Volume fraction on the plateau



Difference between the critical driving force for Fe-C-Cr alloys and the barrier for a diffusional process

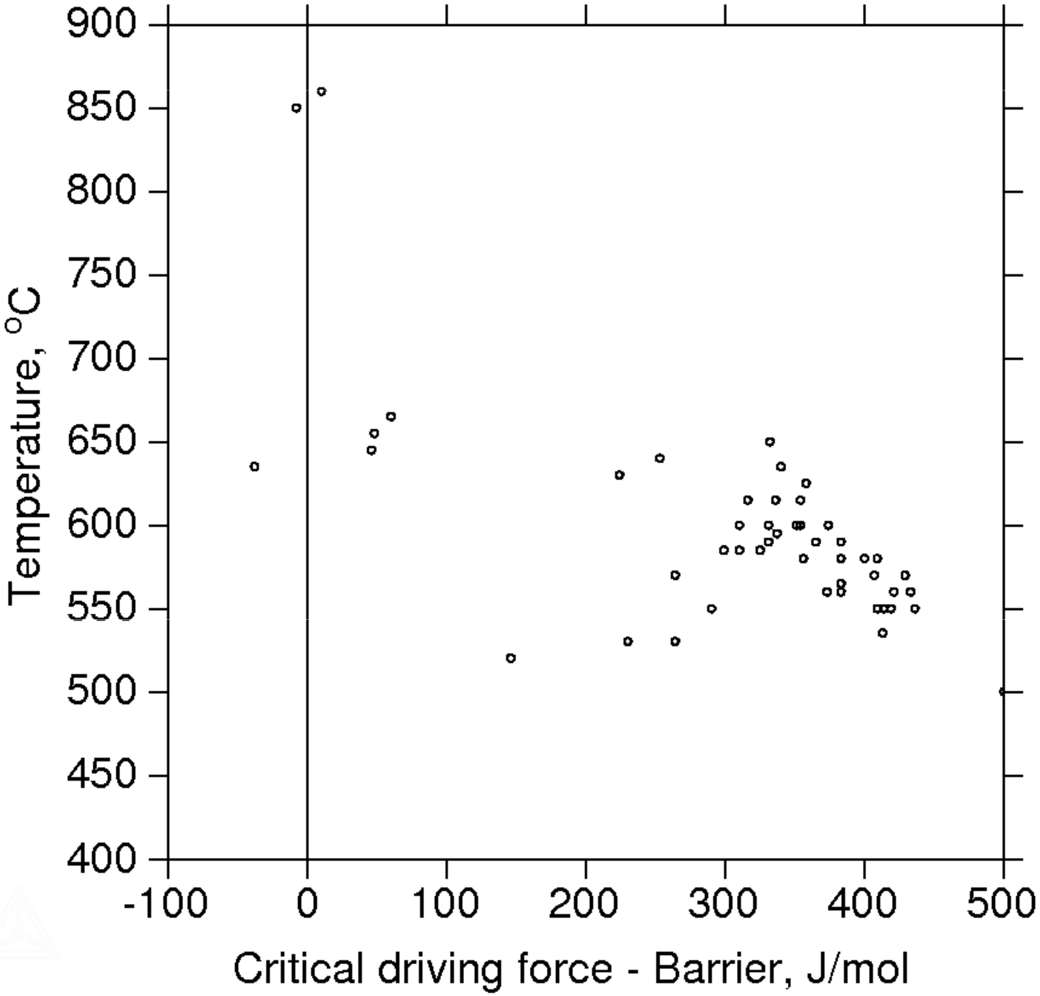


Difference between the critical driving force for Fe-C-Cr alloys and the barrier for a diffusional process divided with the mass% Cr

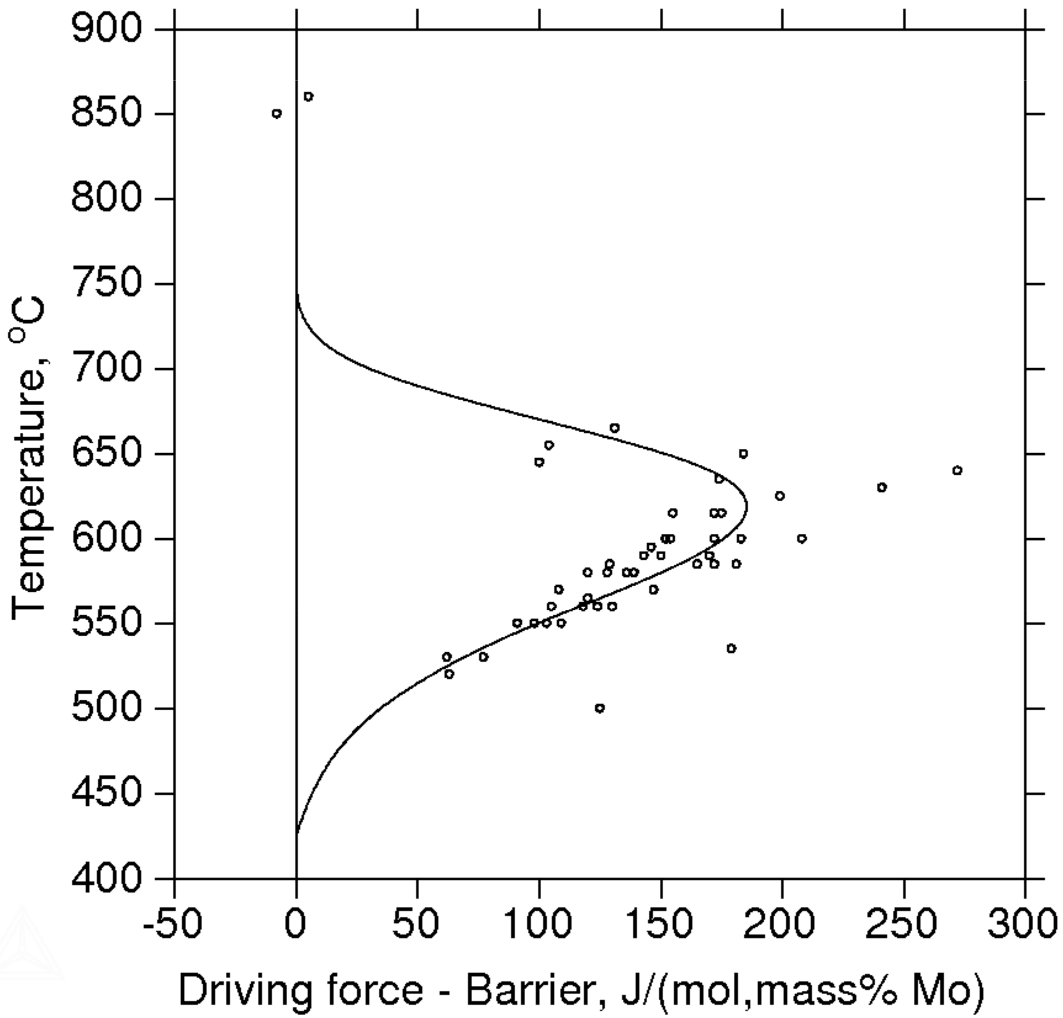


B_{Cr} = mass%Cr $f_{Cr}(T)$ J/mol

Difference between critical driving force and the barrier for a diffusional process in Fe-C-Mo alloys

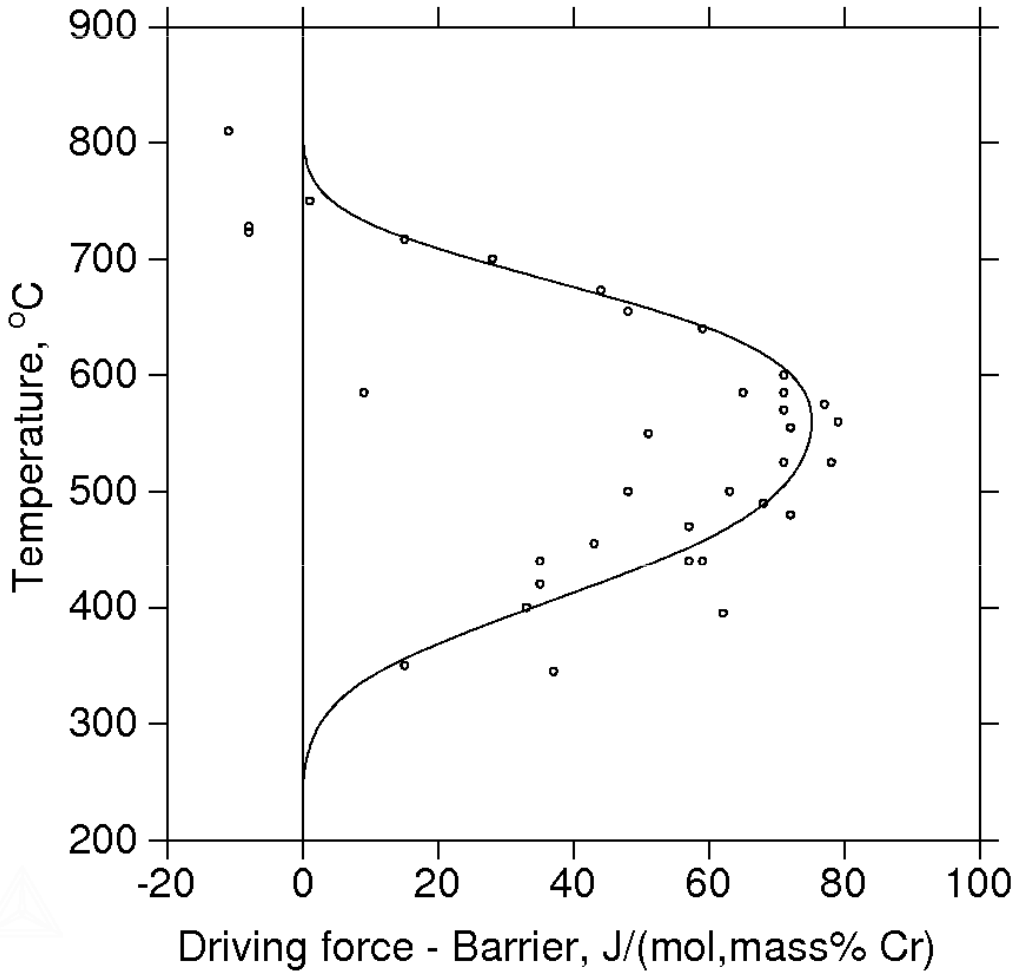


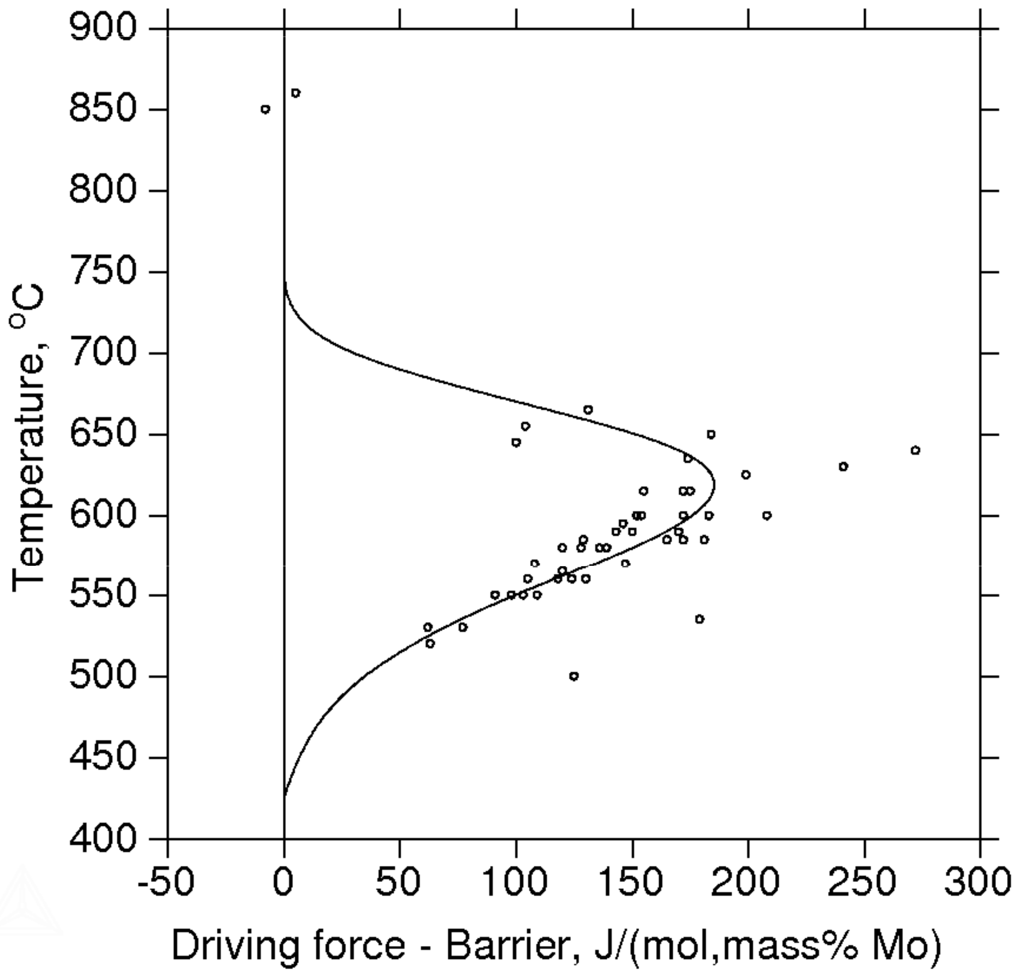
Difference between the critical driving force for Fe-C-Mo alloys and the barrier for a diffusional process divided with the mass% Mo



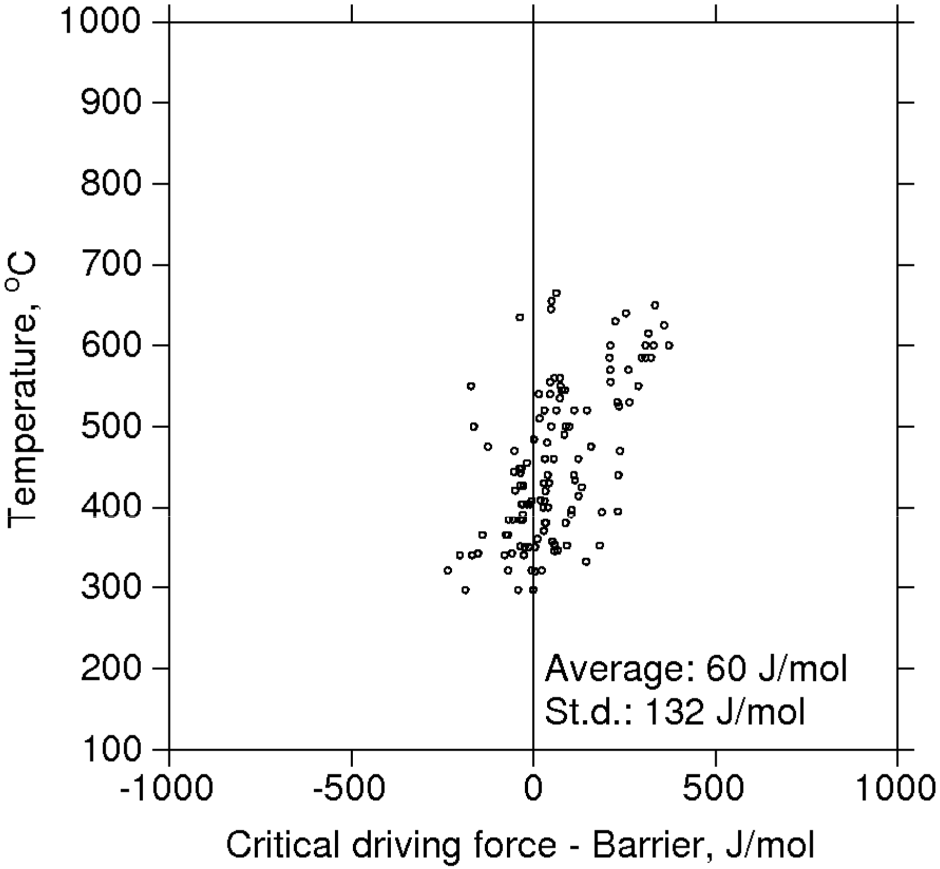
B_{Mo} = mass%Mo $f_{Mo}(T)$ J/mol

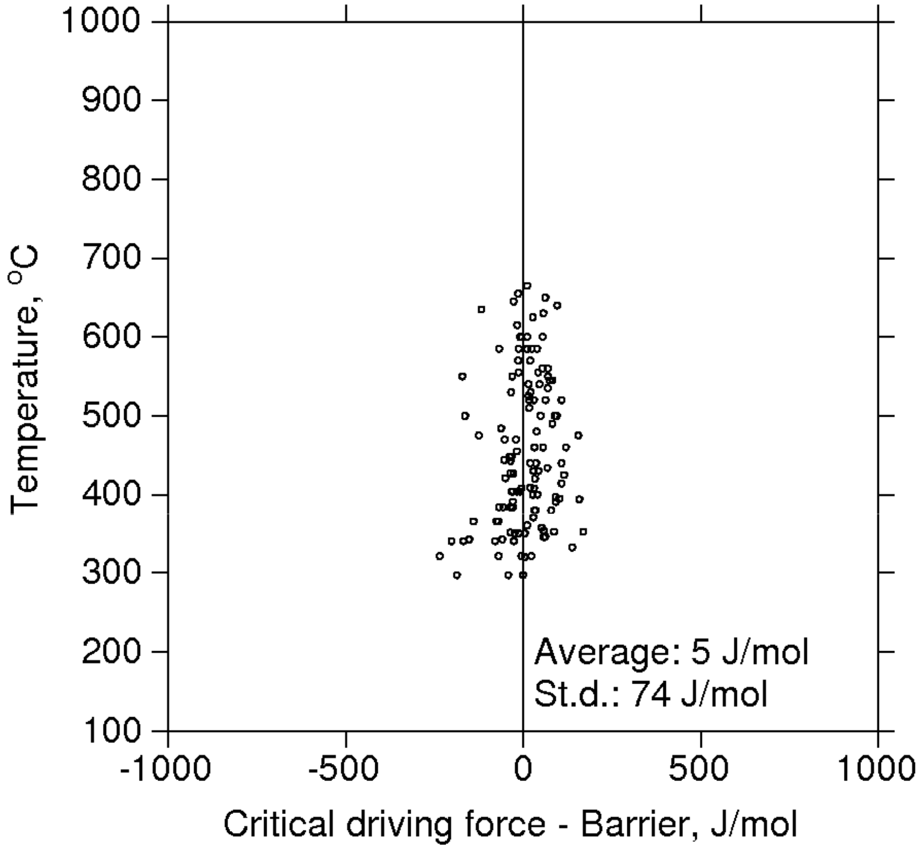
Difference between the critical driving force for Fe-C-Cr/Mo alloys and the barrier for a diffusional process divided with alloying content





Change when adding barriers for Cr and Mo to data from volume fraction on the plateau





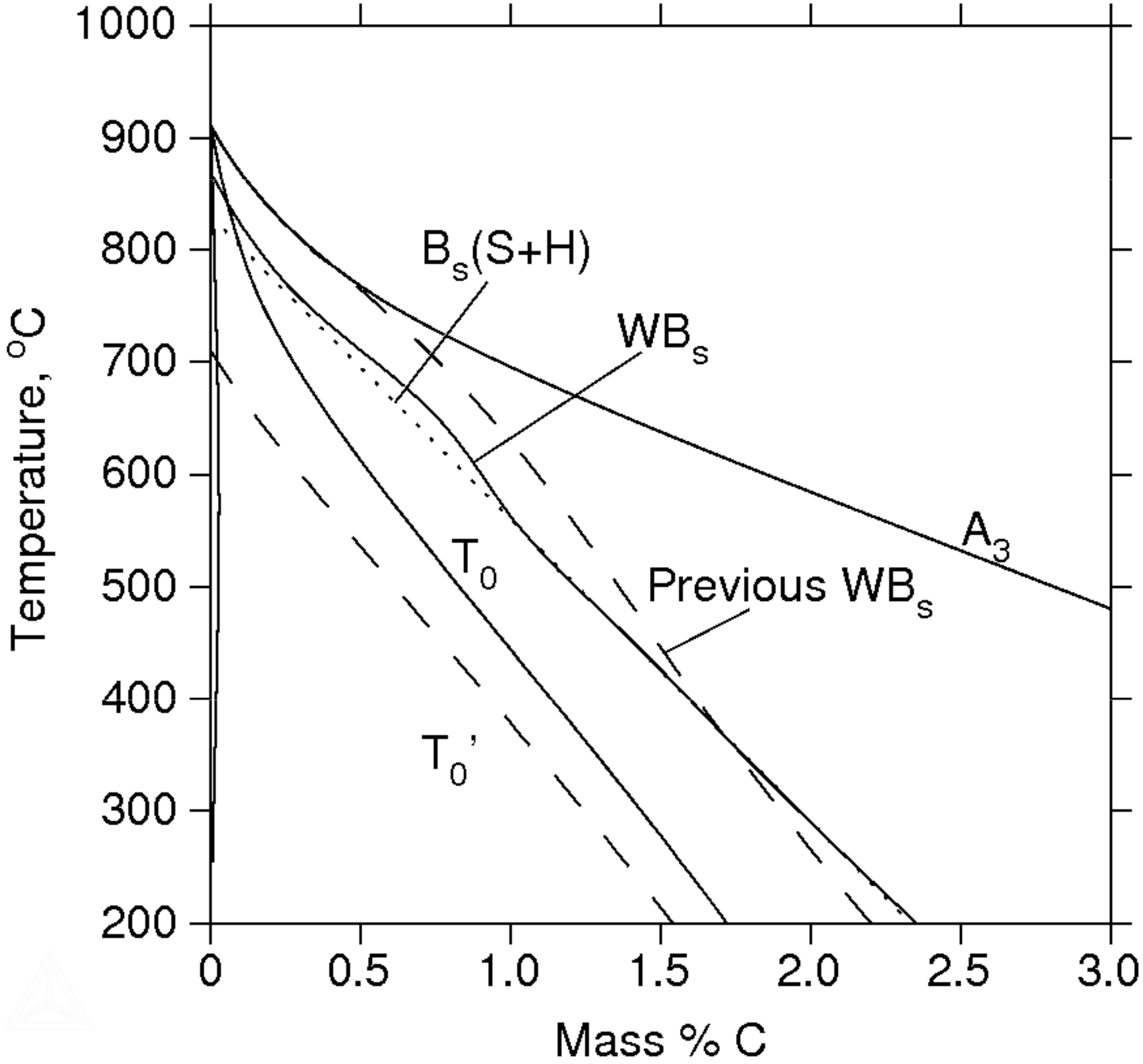
Comparison of predicted and experimental values for WBs

Method	Number of entries	Diffusional with $B_{FeC}+B_{Cr}+B_{Mo}$	Diffusionless B_N in Eq. 4	Bhadeshia B_{Bh} in Eq.4
T1	24	9±84	39±113	-136±94
T2	5	10±16	105±44	19±39
T3	44	-15±96	72±63	-11±54
T4	44	8±74	178±64	57±79
All T	117	-1±84	107±95	-10±102

Comparison of predicted and experimental values for the critical carbon content

Method	Number of entries	Diffusional with $B_{FeC}+B_{Cr}+B_{Mo}$	Diffusionless with B_N in Eq.4	Bhadeshia with B_{Bh} in Eq. 4
C1	2	0.00±0.14	-0.40±0.01	-0.63±0.04
C2	99	0.02±0.19	0.34±0.22	0.11±0.22
C3	160	-0.08±0.34	-0.06±0.29	-0.27±0.29
C4	14	0.13±0.19	0.47±0.18	0.26±0.18
C5	24	-0.04±0.12	0.19±0.36	-0.03±0.36
All C	299	-0.03±0.28	0.12±0.34	-0.10±0.34

Comparison of critical lines for formation of acicular ferrite in Fe-C



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Result and conclusions

- Comparison of experimental and predicted WBs - 18±85 K.
- Thermodynamic facts indicate that acicular ferrite in bainite and Widmanstätten ferrite are formed by the same process.
- Thermodynamic facts indicate that the formation of acicular ferrite is controlled by carbon diffusion.
- No significant difference between different type of experimental data was observed.
- New information on Fe-C is needed.

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THANK YOU FOR YOUR ATTENTION!

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