Alloying Elements

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Materials Engineering
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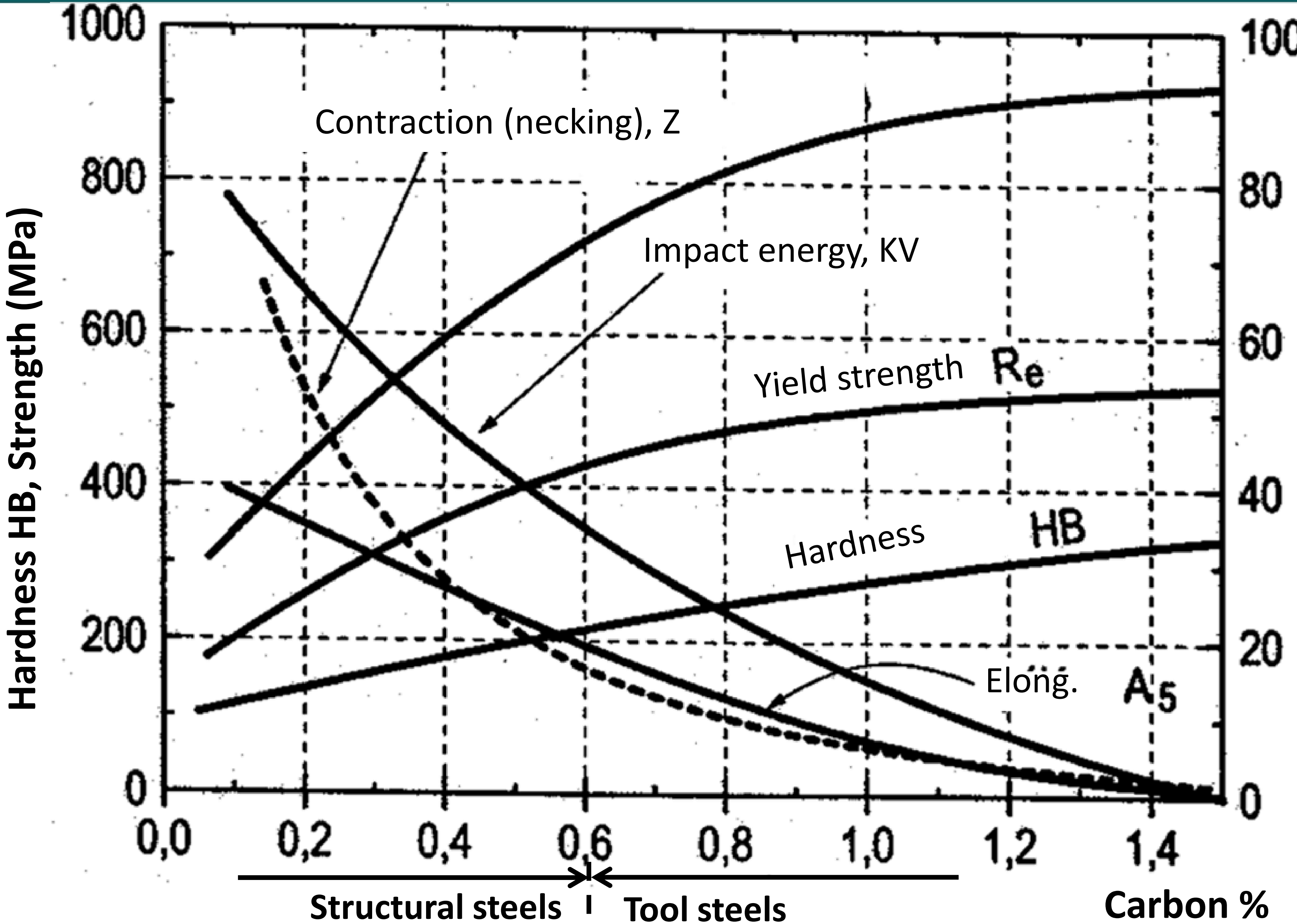
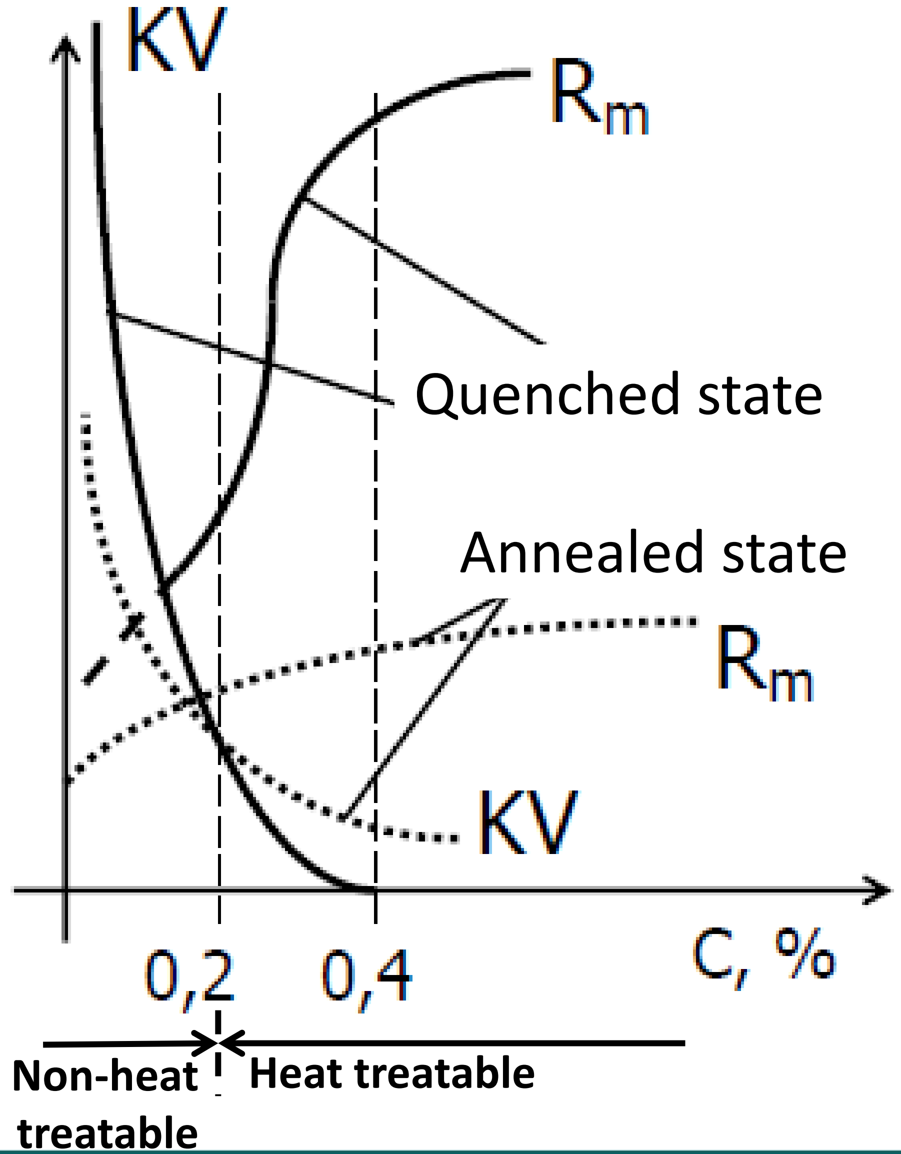
Basic alloying elements and impurities

- Basic alloying elements
  - C – primer alloying element in most of the steels and cast irons
  - Mn – solid-solution strenghtening, deoxidizer, weak austenite promoting element
  - Si – deoxidizer, ferrite promoting element
  - + Ni, Mo, Co, Cr, W, Cu
  - + Al, Ti, V, Zr, B, Ce, Ca, Nb – microalloys
- Impurity elements
  - S – brittleness, sulfides
  - P – brittleness at high temperatures
  - O, H, N – brittleness, ageing, gas porosities
  - + As, Sb, Se, Bi, Sn, Pb

The effects of carbon – annealed state



The effects of carbon – quenched state



http://www.indianagroup.com/fabricated-steel-structures/

Steel structures

The effects of alloying elements on the properties of steel

1. Solubility → ferrite or austenite producing elements
2. Non-equilibrium γ → α transformation
3. Austenite grain growth
4. Softening during tempering
5. Embrittlement during tempering
6. Ductile-brittle transition temperature
7. Recrystallization's temperature

1. Does it dissolve in the steel?

Does not dissolve

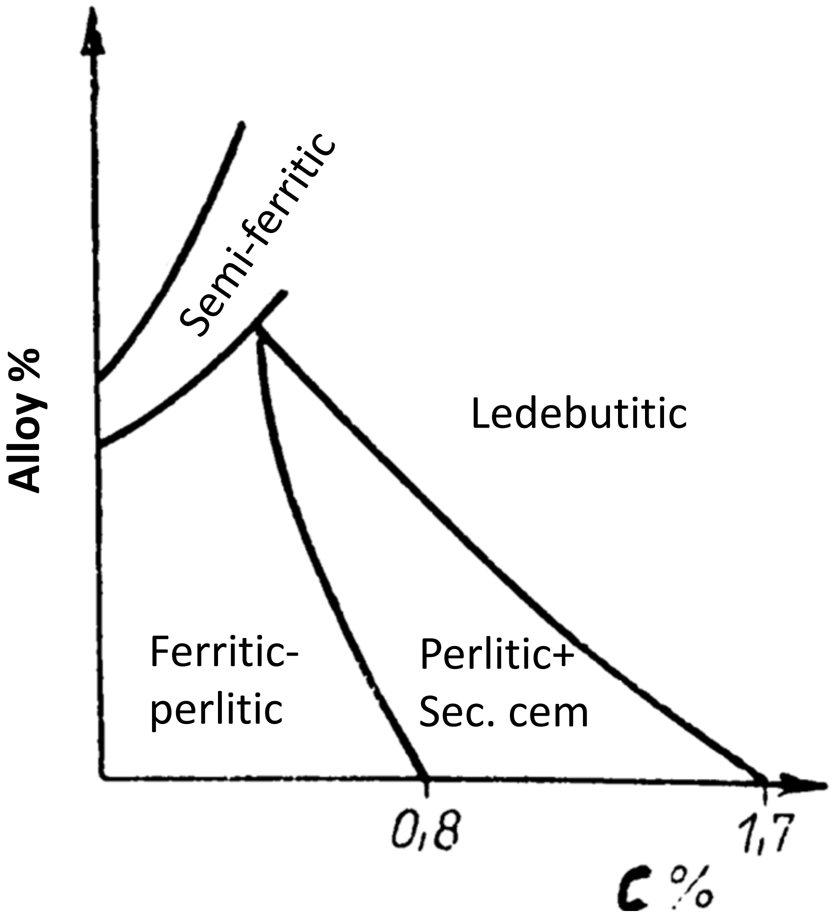
- Produces inclusions, disadvantageous
- S, As, Pb…

Dissolves

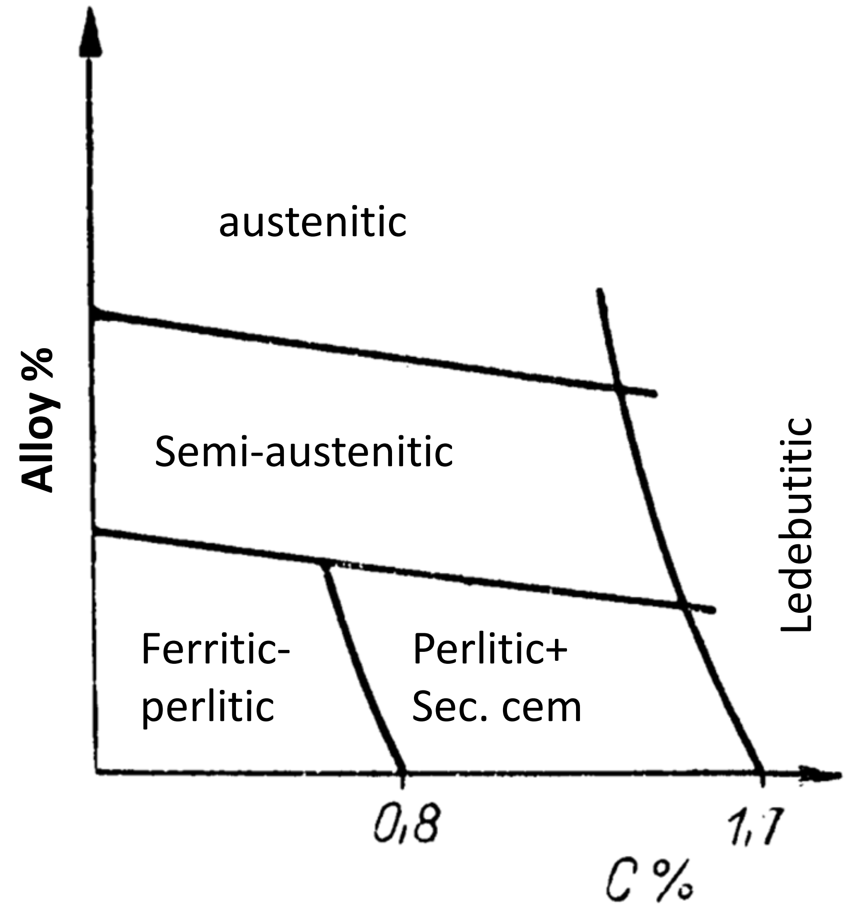
- Dissolves better in ferrite – ferrite promoting element
- Cr, Al, Si, W, Mo, V, Ti

- Dissolves better in austenite – austenite promoting element
- Ni, Mn, C, N, Cu

Microstructure, C and alloy content

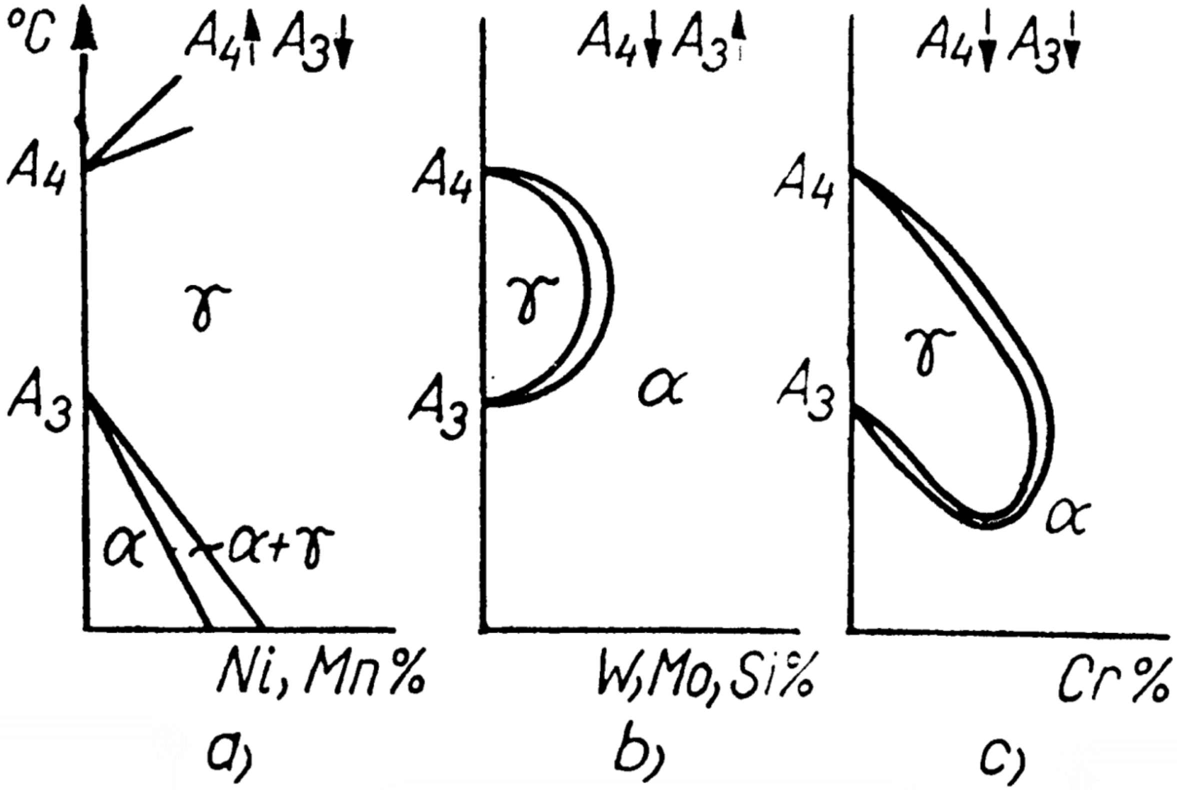


Ferrite promoting element



Austenite promoting element

Change of transformation's temperature

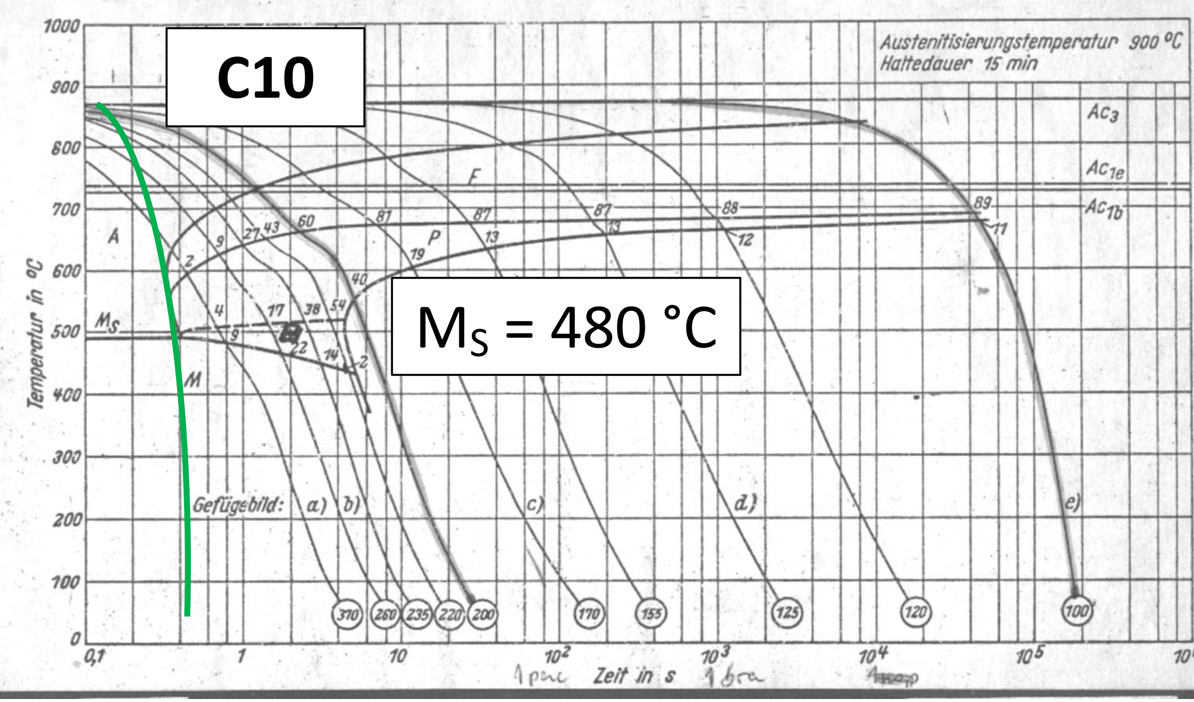


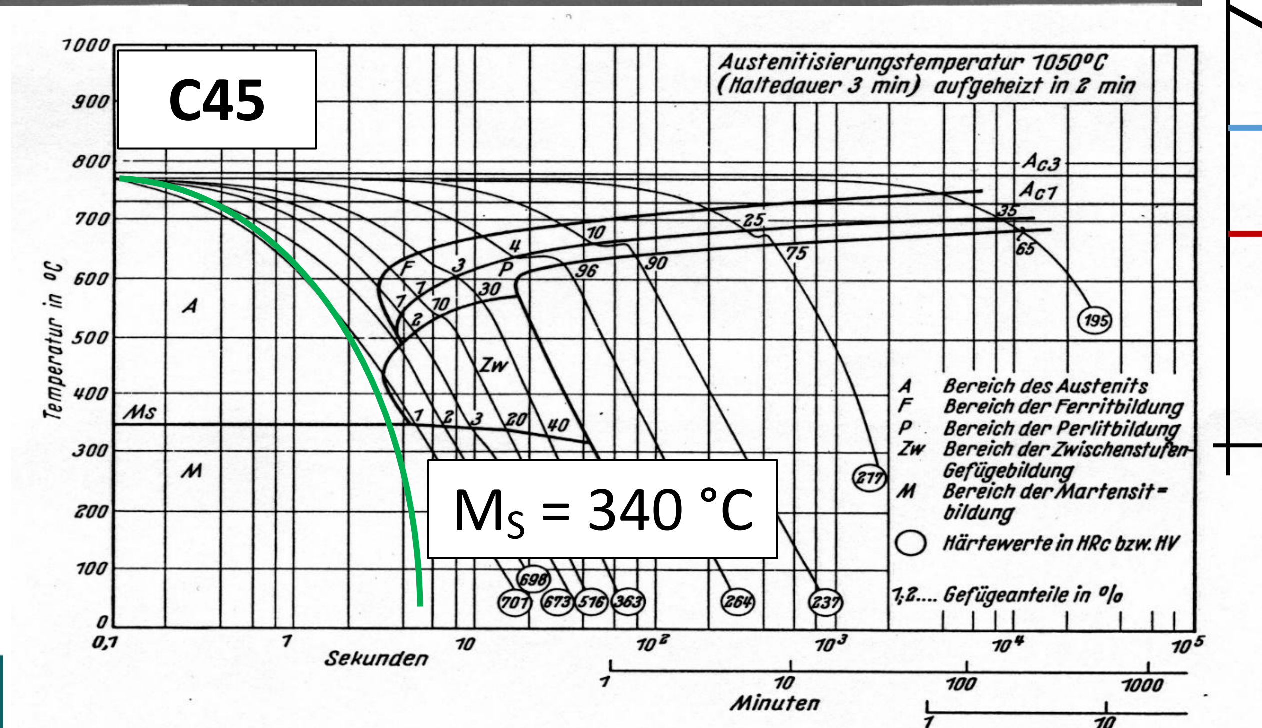
- All alloying elements decreases the Ms and Mf temperatures, except Co and Al.
- The present of residual austenite increases.
  - Deep cooling if necessary
- The CCT curves are shifted to the right.
  - The critical cooling rate is decreasing.
- Hardenability, through hardening diameter increases.

Conditions of quenching

- Importance of quenching: with quenching & tempering (allotropic transformation) the properties can be influenced in wide range.

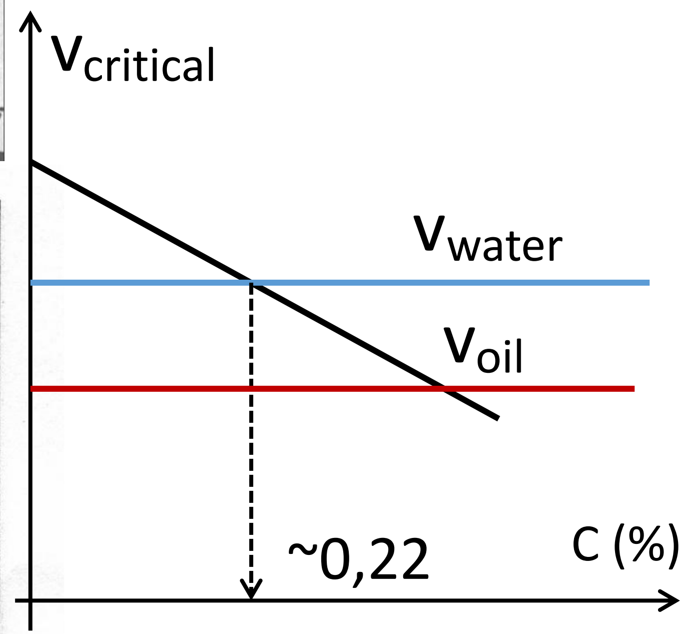
- Conditions
  - Heating to the temperature of A_3 + ~50°C
  - Keeping at constant temperature till material is fully austenitized
  - Cooling faster than the critical cooling rate
  - Practical condition: C > 0.2%





Practical conditions

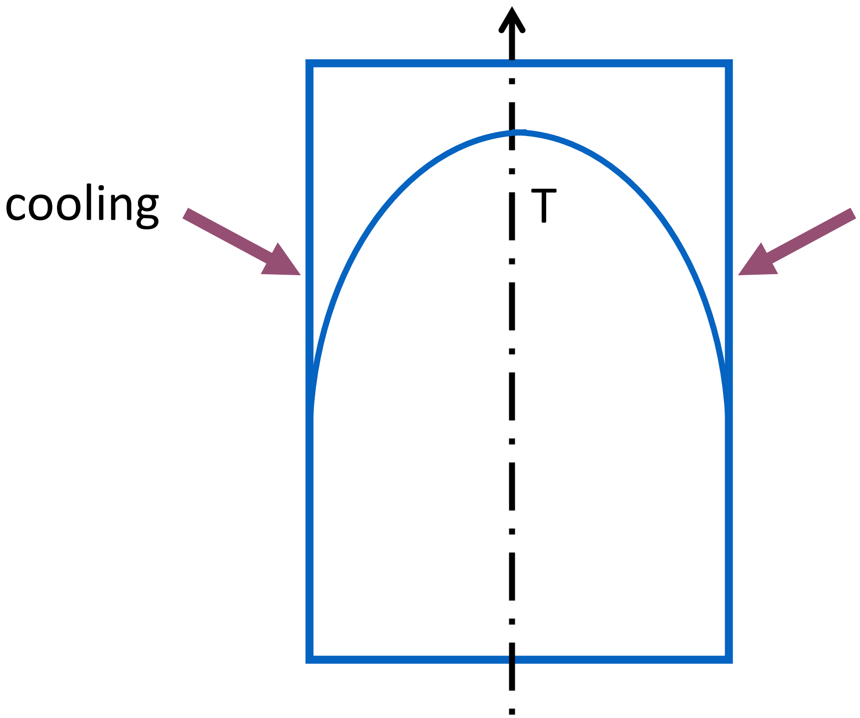
The alloying decreases the critical cooling rate and the M_s temperature.



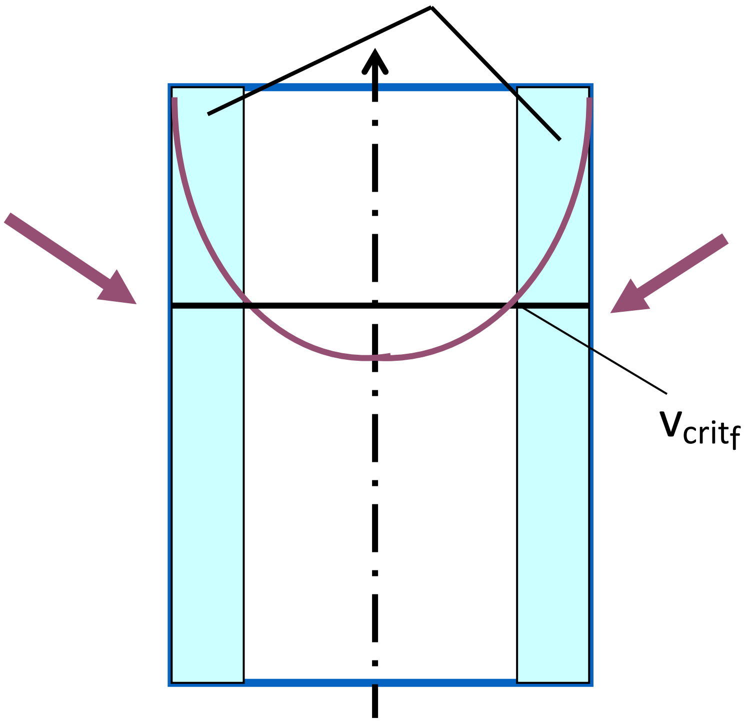
Effect of through hardenability

The maximal diameter of a bar, which can be quenched to contain 50 % of martensite.

(see more: lab practice…)



Temperature distribution



Distribution of cooling rate

The maximal diameter of a bar, which can be quenched to contain 50 % of martensite.

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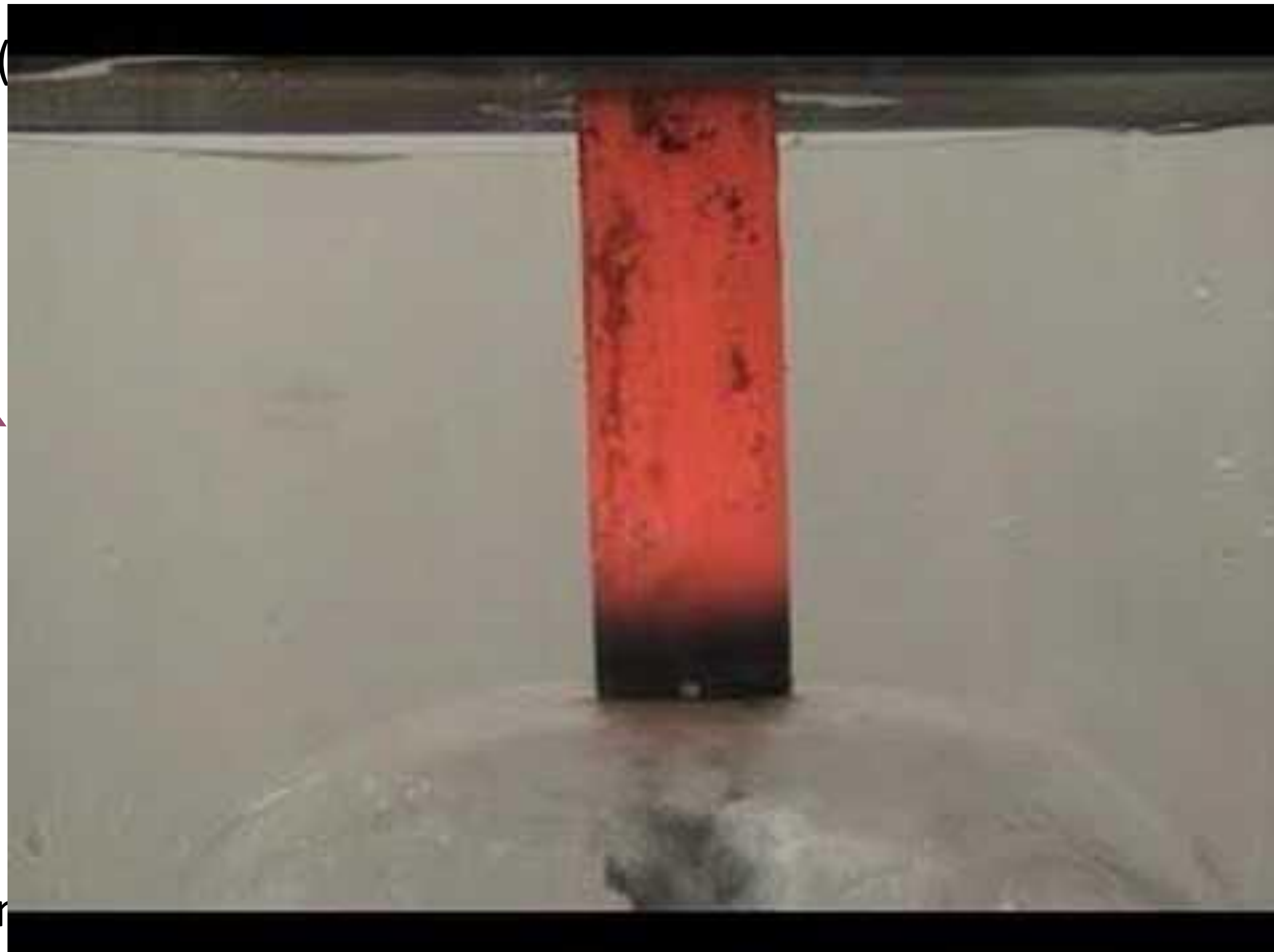
layer

cooling



v_{critf}

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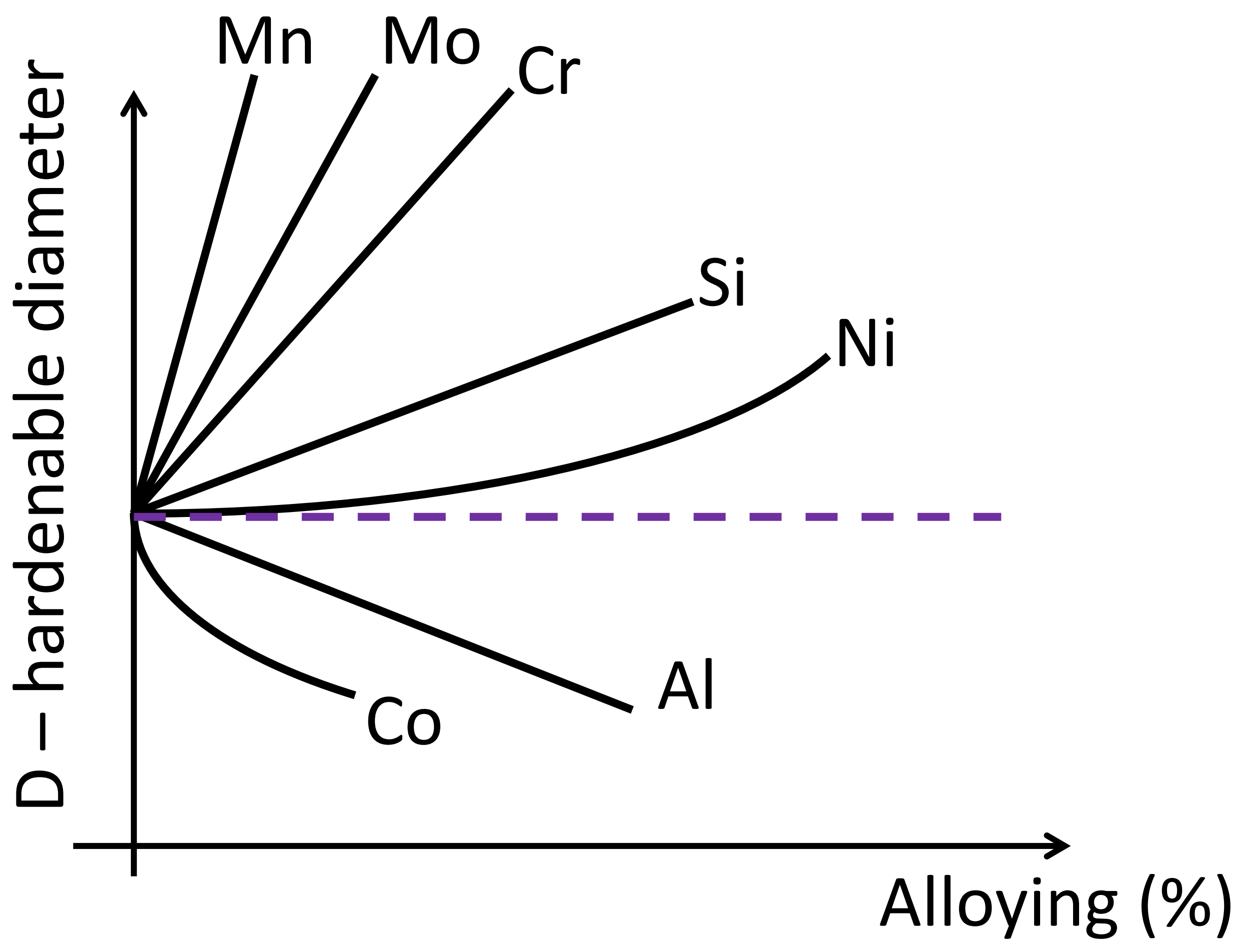
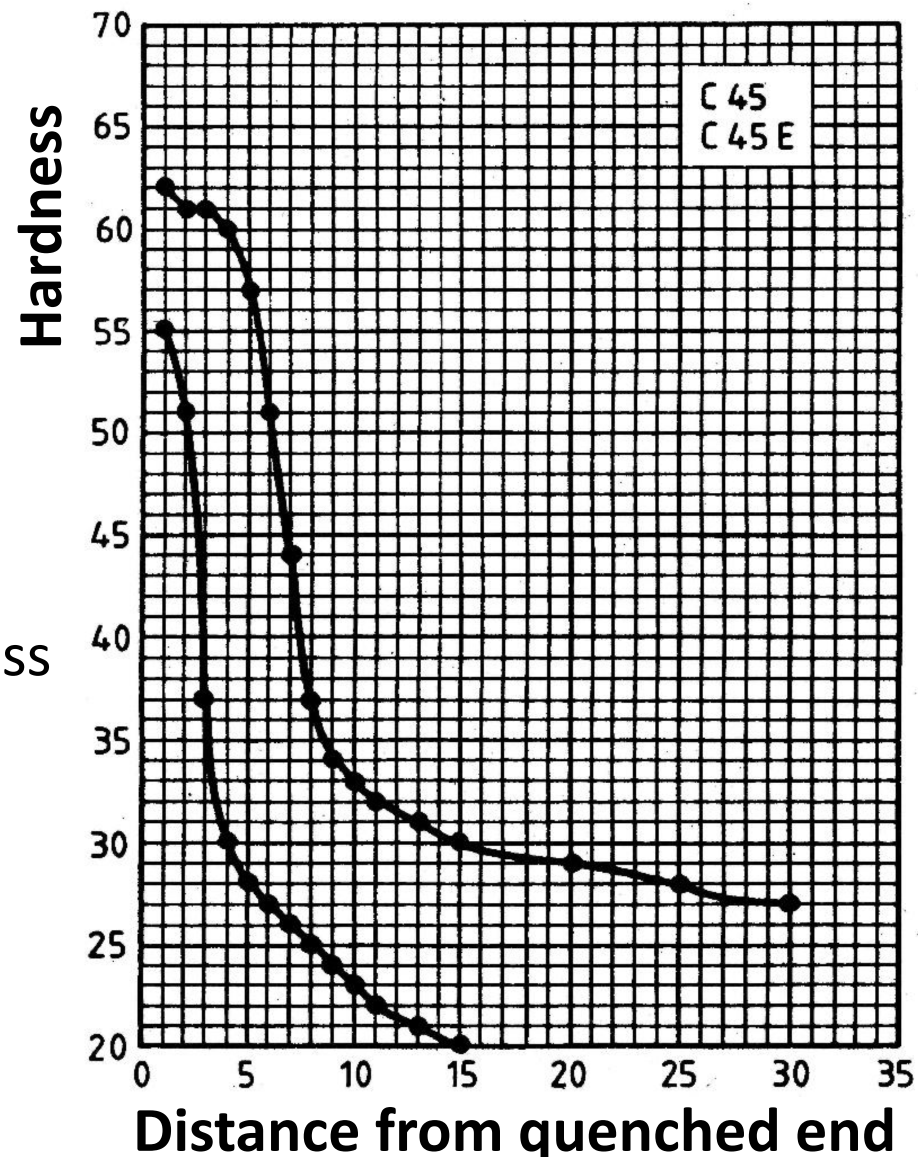
The effects of alloying elements on hardenability



Application of Jominy test results

- Verification of material
  - Hardness according to the standards
- Technology information
  - Maximal/minimal hardness by quenching
  - Hardness distribution in the cross section



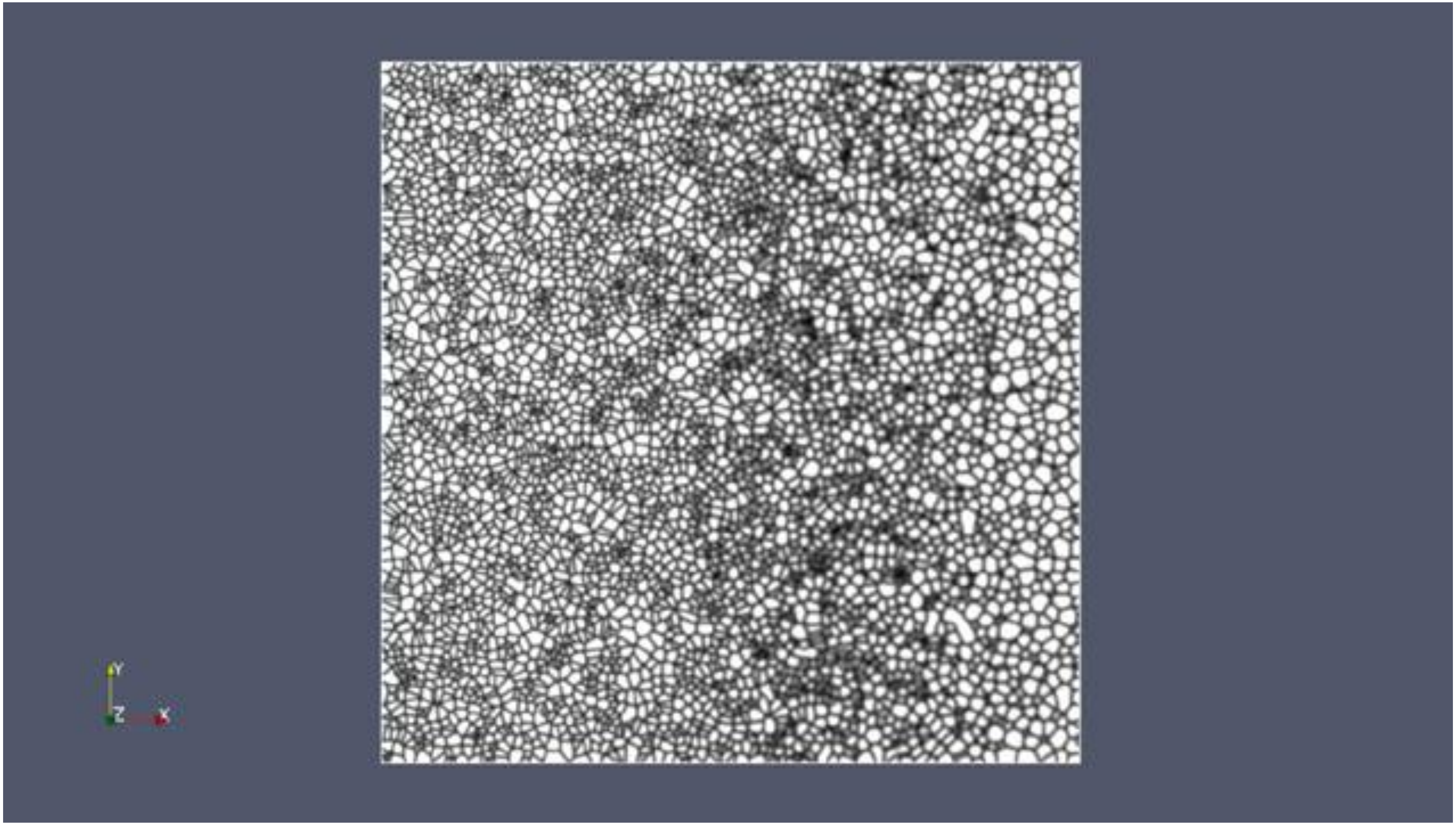
3. The effect of alloying on the austenite grain growth

- Mn, Si and B increases the susceptibility to grain coarsening

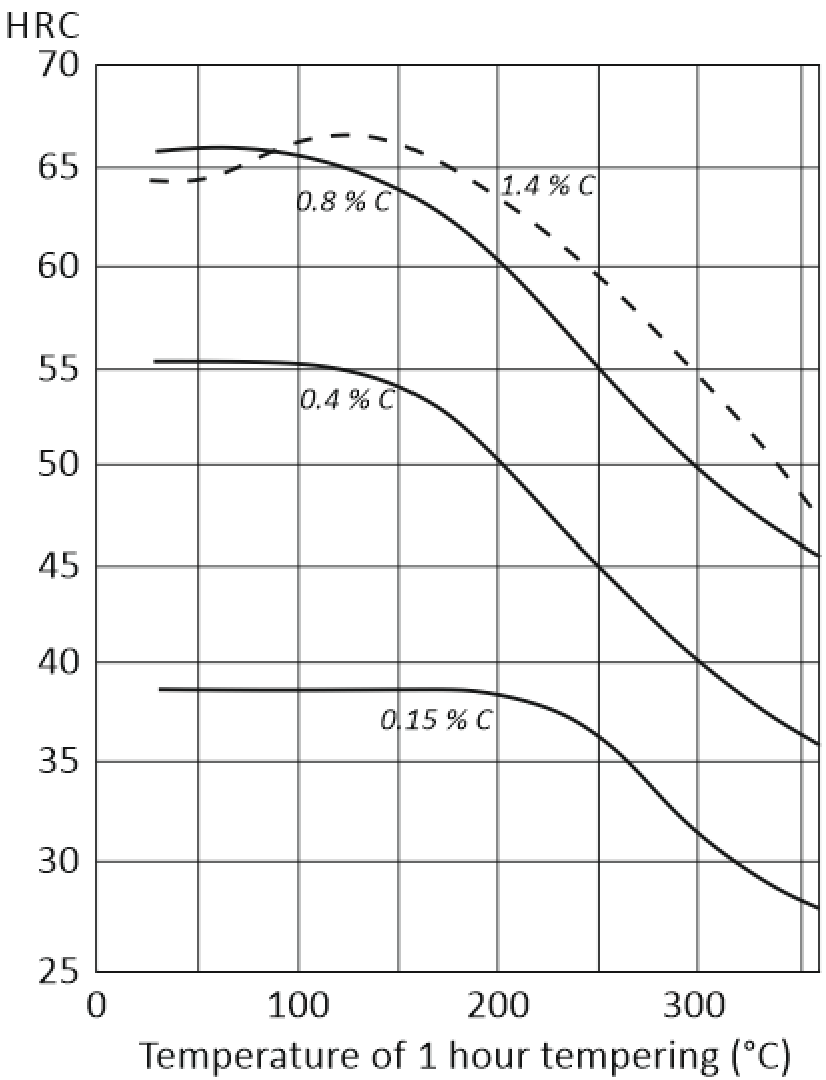
- Grain refining effect: Ti, V, Nb, Al, Zr
  - Producing fine uniformly distributed nitro-carbides on the grain boundaries, what decreases the boundary migration.

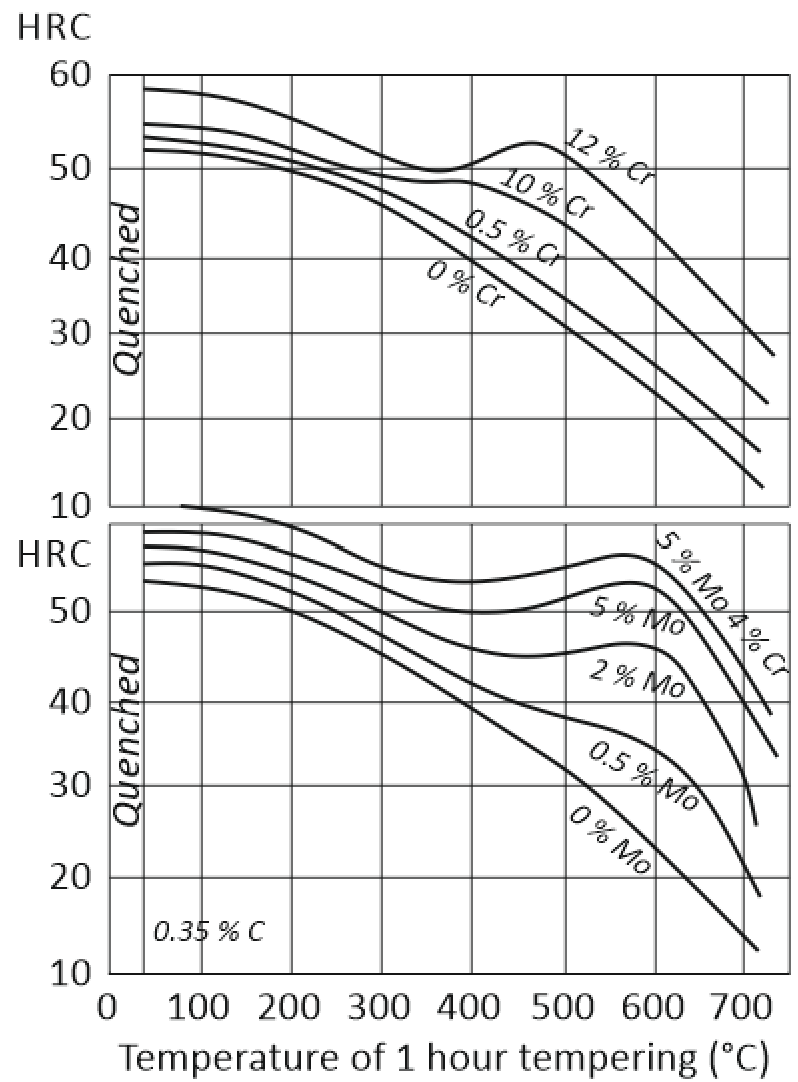
- Other alloying elements have no significant effect of grain coarsening.

3. The effect of alloying on the austenite grain growth

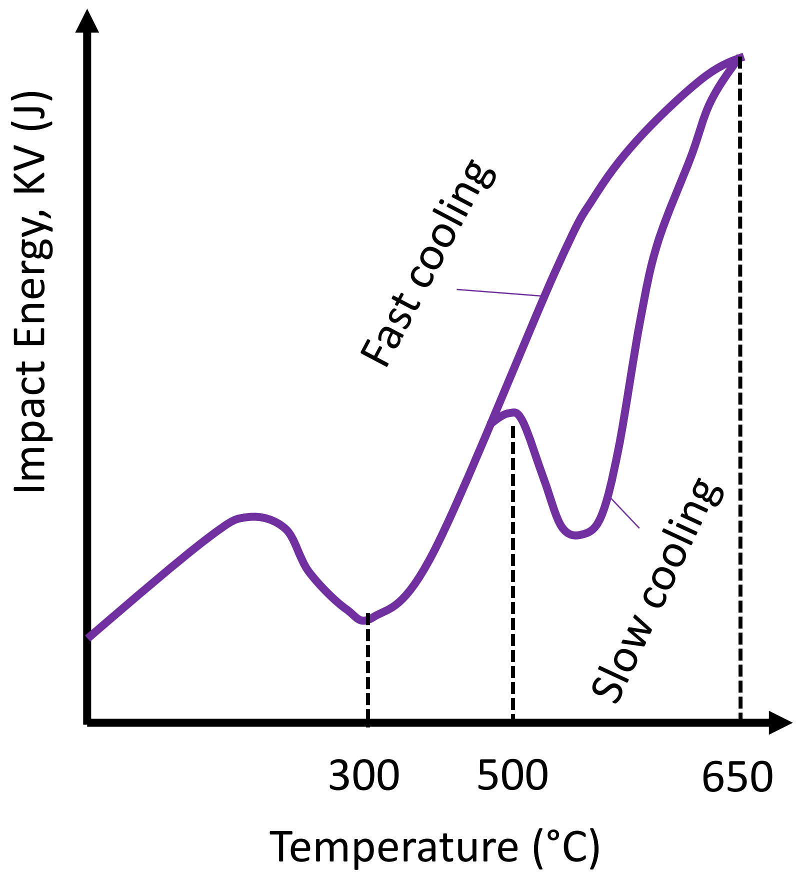


4. The effect alloying on softening during tempering





5. The effect of alloying on the embrittlement during tempering



- Cr, Mn causes brittleness if slowly cooled at 500-650 °C
- Reason: Enrichment of carbides, nitrides, phosphides at grain boundaries
- P makes it worse.
- Ni together with Cr and Mn is disadvantageous
- 0.2…0.3 % Mo or 0.5-0.7 % W and fast cooling is advantageous.

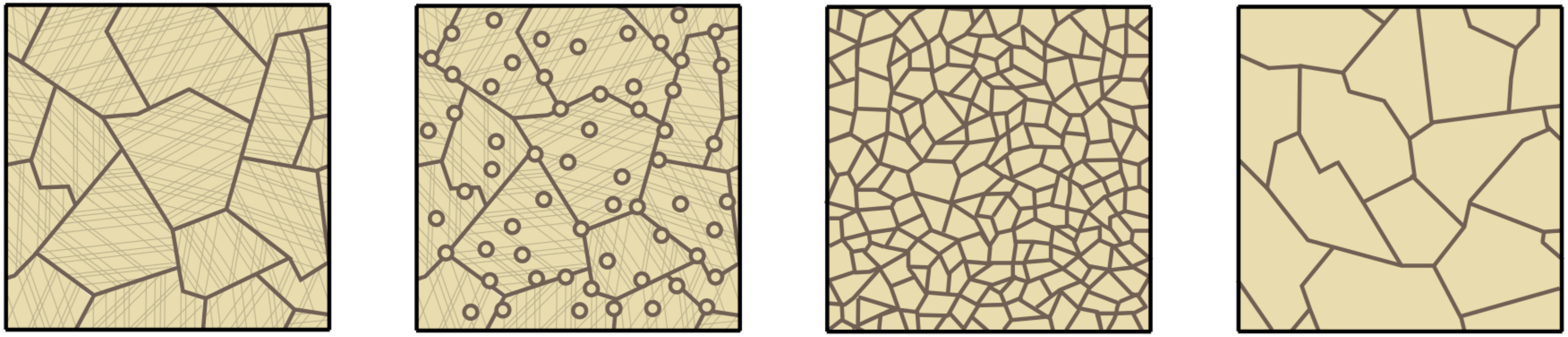
- Ni alloying shifts the impact energy–temp. diagram to the left.
  - 1% Ni alloying ~20°C shift

- Grain refinement helps as well
  - Nb, V, Ti, Al, Zr, N microalloying ~40°C effect

- Impact energy–temp. diagram is shifted to right (makes it worse)
  - C, 0.1% C ~25°C
  - P, 0.1% P ~55°C
  - N, 0.01% N ~300°C (as solution)
  - O, 0.01% O ~200°C (as solution)

7. The effect of alloying on the recrystallization temperature

- The alloying increases the heat and creep resistance.
  - W, Mo ~110°C / at%
  - V ~55°C / at%
  - Cr ~30°C / at%



(a) (b) (c) (d)

Thank you for your attention!