Department of Materials Science and Engineering

Alloying Elements

Balázs Varbai, PhD, EWE/IWE

Materials Engineering
BMEGEMTBGF1
2022 Fall semester

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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

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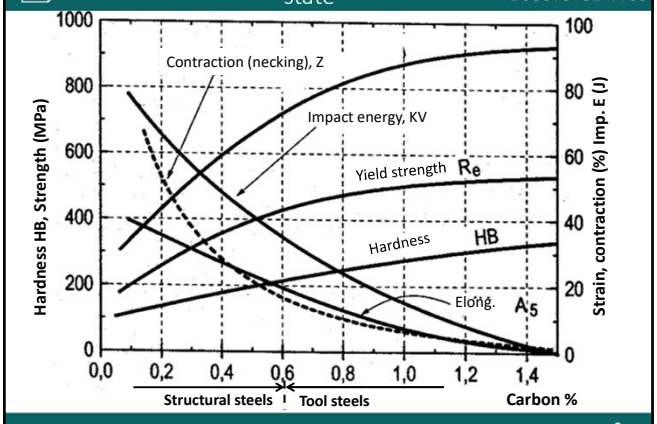
The effects of carbon – annealed state



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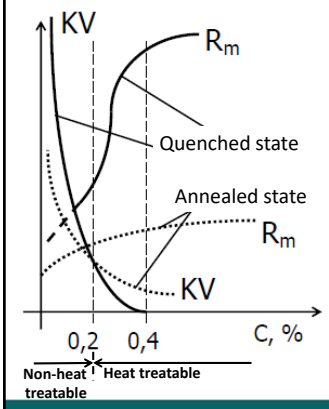
The effects of carbon – quenched state



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

Steel structures

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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

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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

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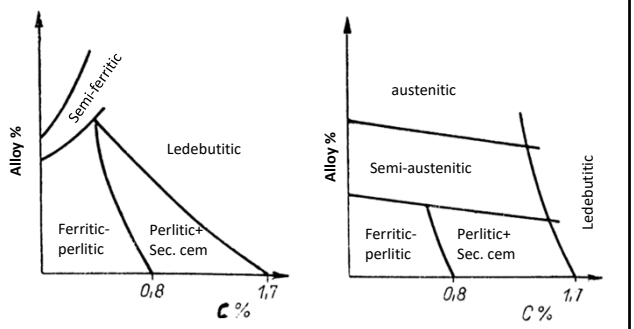
Microstructure, C and alloy content



Ferrite promoting element

Austenite promoting element

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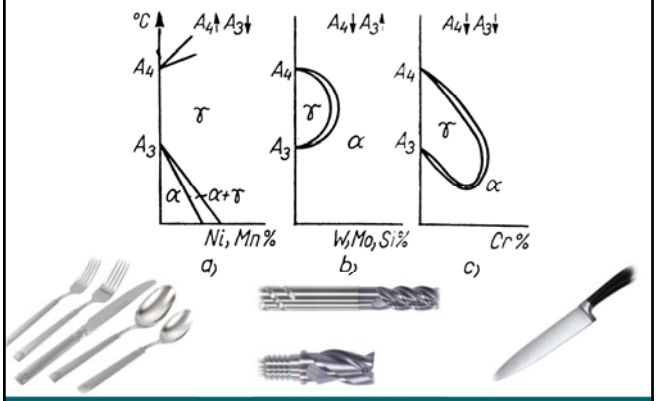
Change of transformation's temperature



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2. Effect of alloying elements on non-equilibrium transformation

- 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.

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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%

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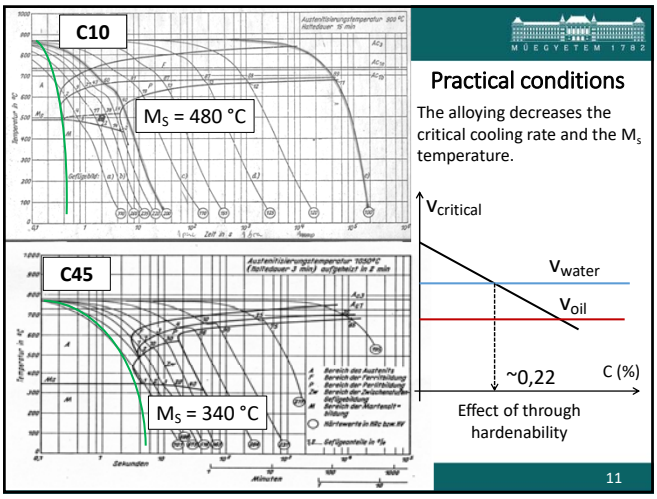

Practical conditions

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

Effect of through hardenability

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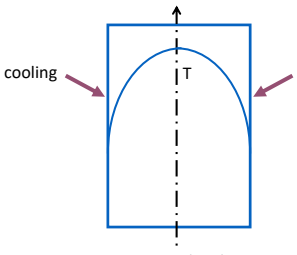
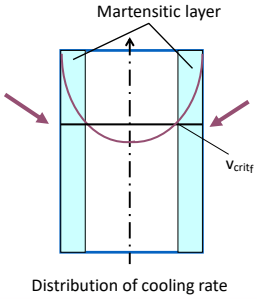
Hardenability

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

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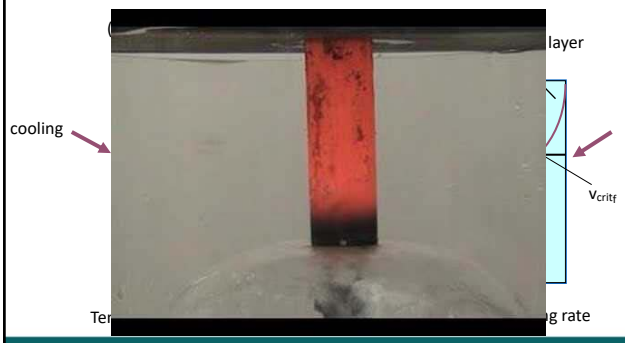
Hardenability

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



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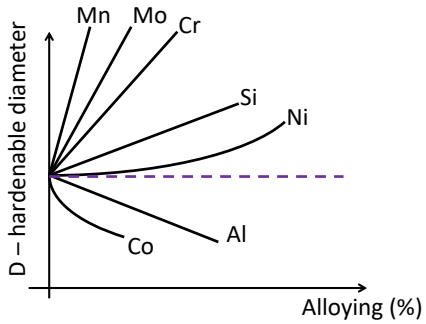
The effects of alloying elements on hardenability



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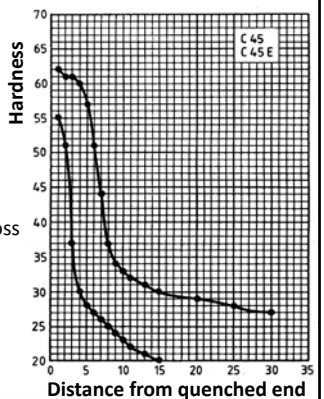
Application of Jominy test results

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



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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.

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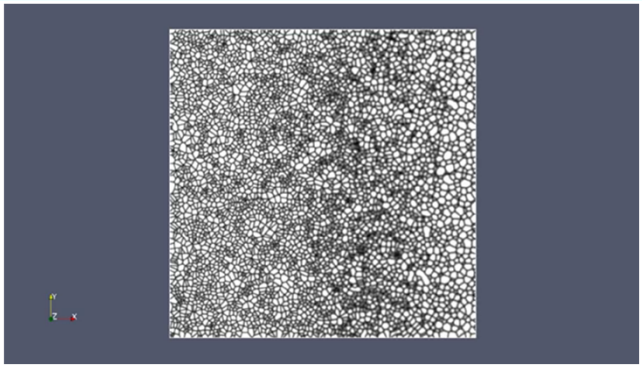
3. The effect of alloying on the austenite grain growth



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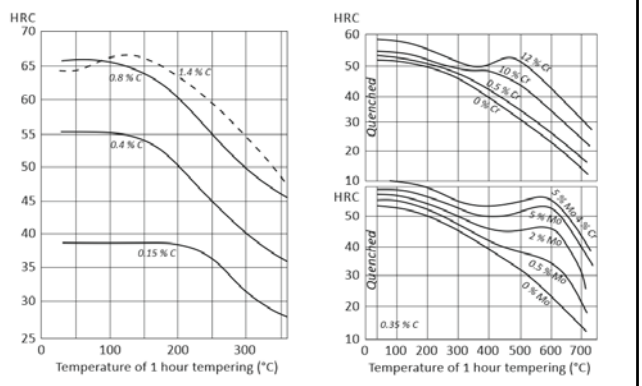
4. The effect alloying on softening during tempering



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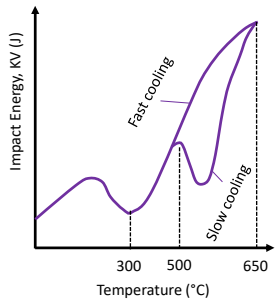
5. The effect of alloying on the embrittlement during tempering



- 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.

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6. The effect of alloying on the ductile →brittle transition temperature

- 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)

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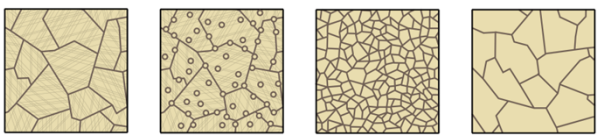
7. The effect of alloying on the recrystallization temperature

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



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Thank you for your attention!