Lecture on Materials Science - Heat Treatment

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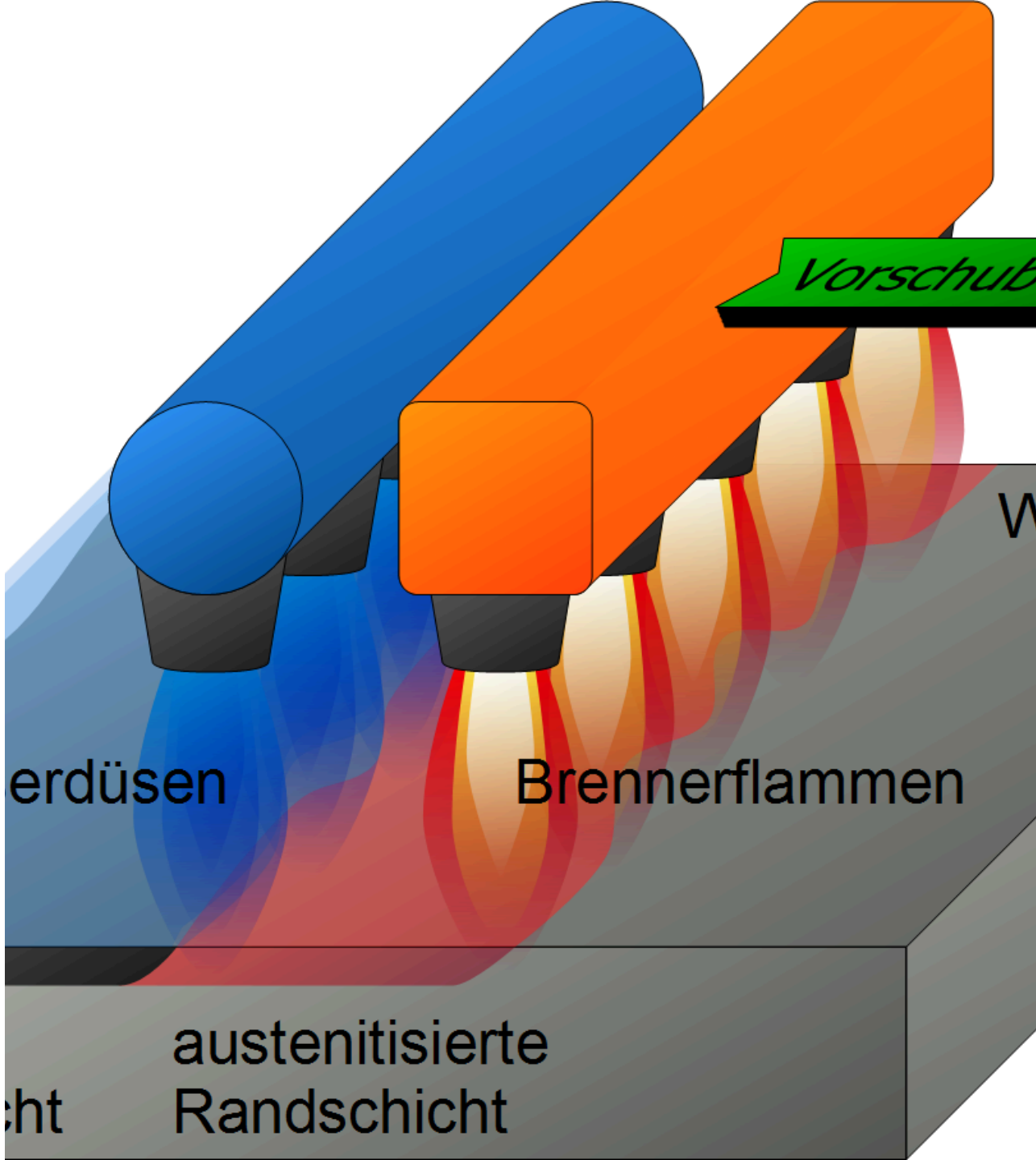
Parts of the script are adopted from
Prof. Dr.-Ing. Jürgen Häberle



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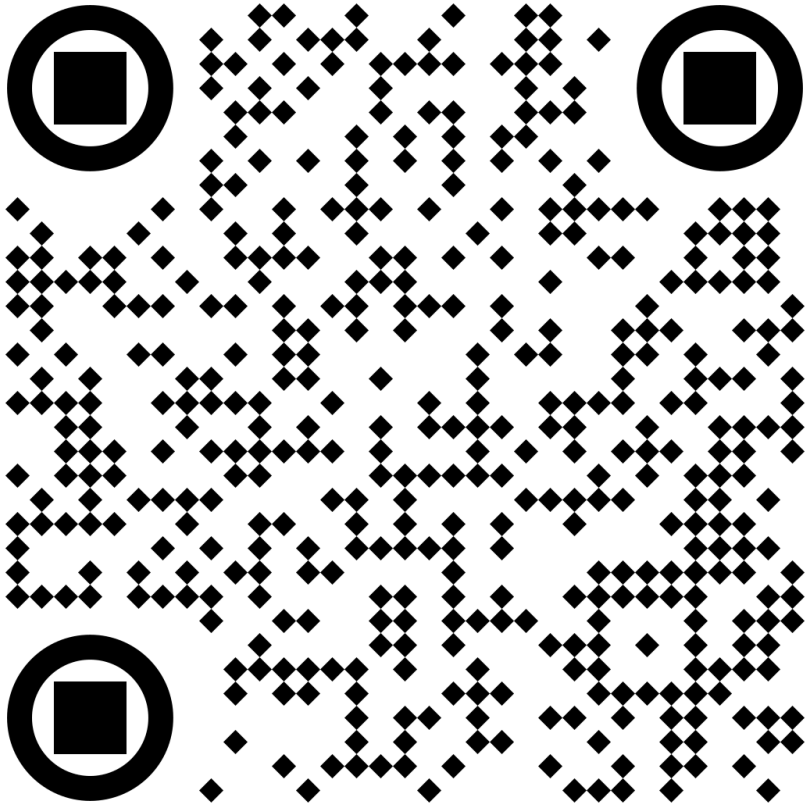


Heat Treatment

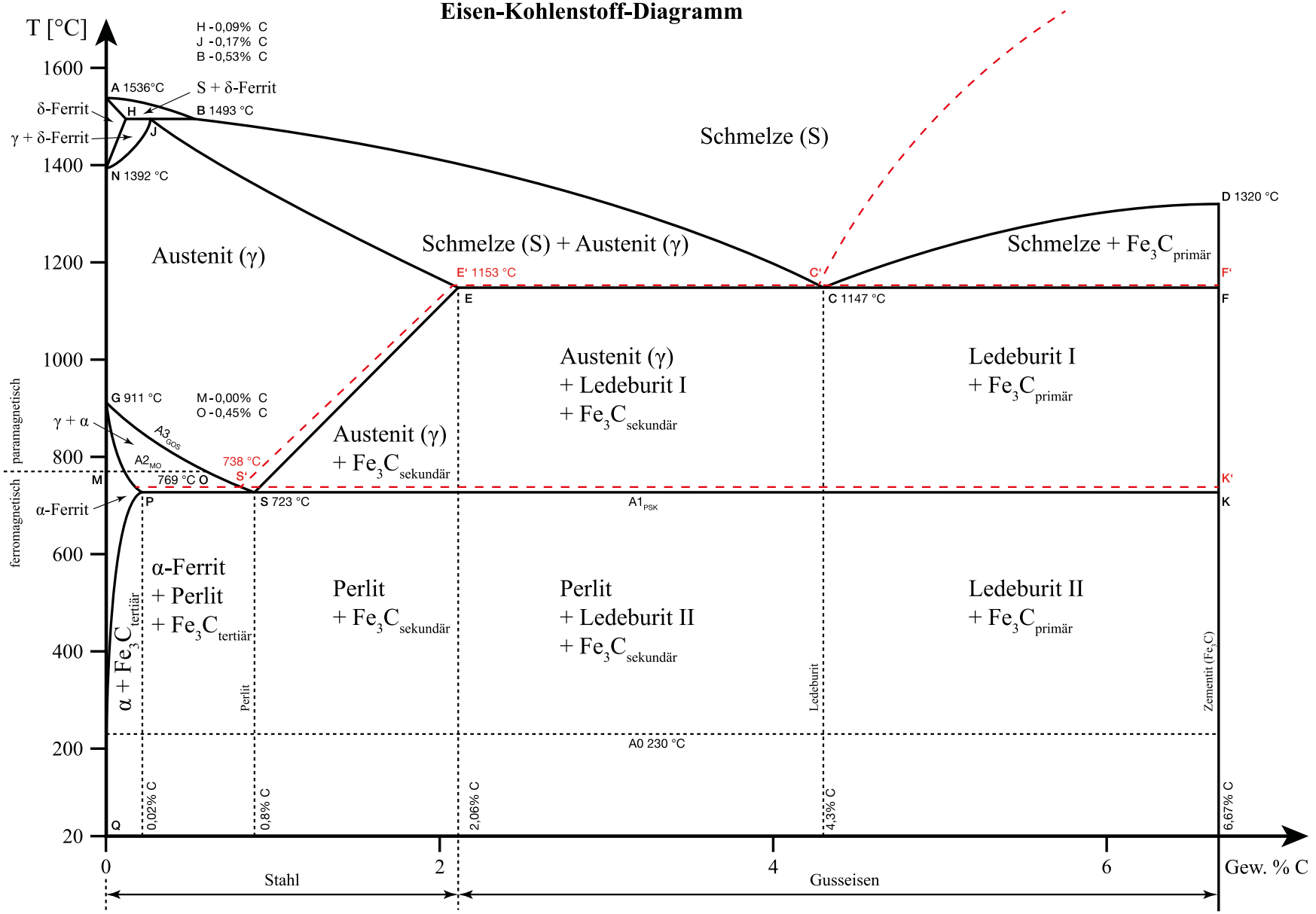
- Annealing processes
- Hardening processes

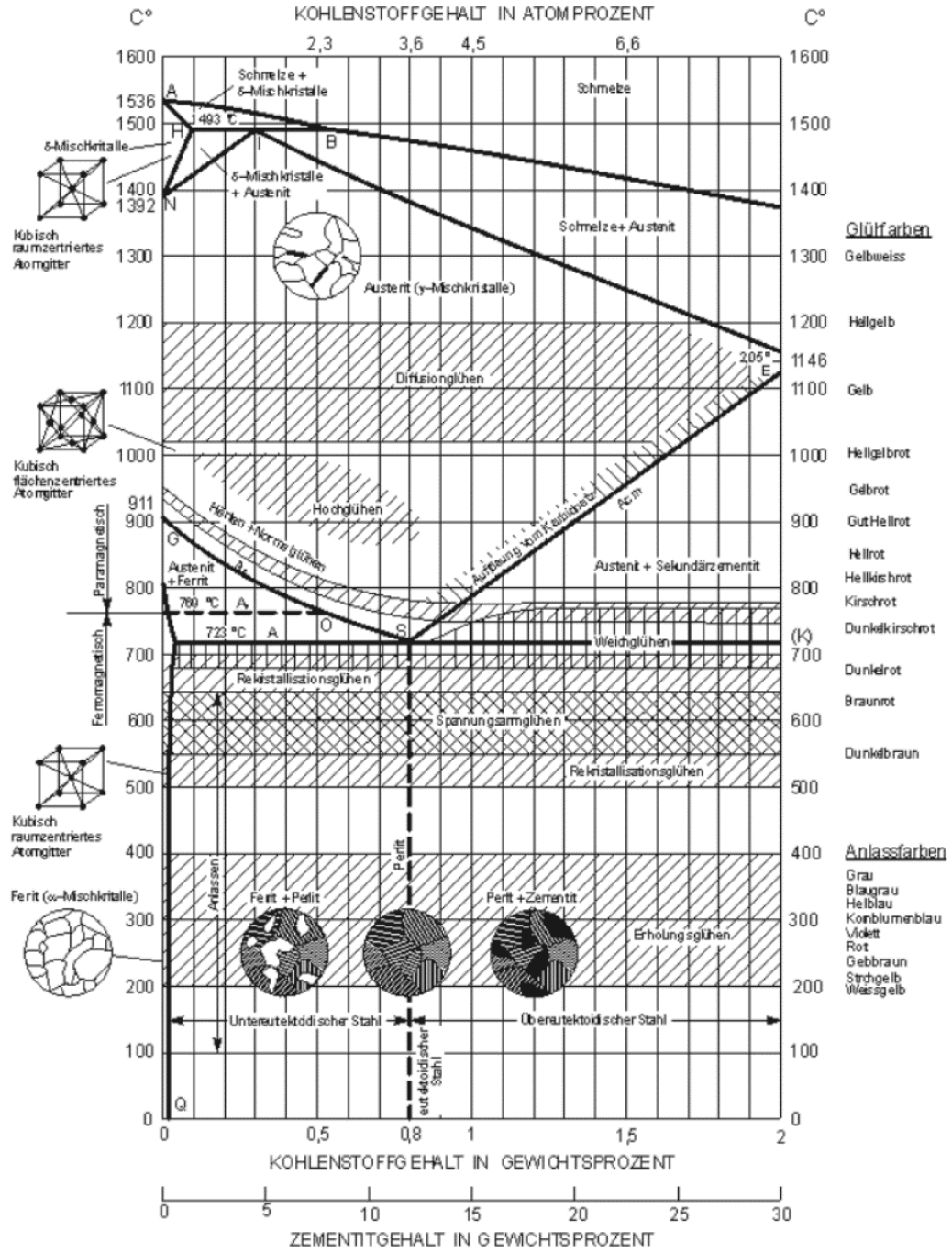
Characterization:

- Type of heating
- Holding temperature
- Holding time
- Type of cooling (furnace, air, oil, water cooling)

Why?

- Improvement of machinability (soft annealing)
- Step in production process (hardening of tools)
- Enhancement of mechanical properties (tempering of steel, aging of aluminum alloys)
- Reduction of wear (surface hardening of gears)
- Elimination of work hardening (recrystallization annealing)
- Reduction of casting or welding stresses (stress-relief annealing)


Eisen-Kohlenstoff-Diagramm
T [°C]
H -0,09% C
J -0,17% C
B -0,53% C
A 1536°C
S + δ-Ferrit
B 1493 °C
δ-Ferrit
H
J
γ + δ-Ferrit
N 1392 °C
Schmelze (S)
D 1320 °C
Austenit (γ)
Schmelze (S) + Austenit (γ)
Schmelze + Fe3C primär
E' 1153 °C
C'
F'
E
C 1147 °C
F
Austenit (γ)
+ Ledeburit I
+ Fe3C sekundär
Ledeburit I
+ Fe3C primär
G 911 °C
M -0,00% C
O -0,45% C
γ + α
A3GOS
A2MO
738 °C
S'
K'
M
769 °C O
Austenit (γ)
+ Fe3C sekundär
P
S 723 °C
A1PSK
K
α-Ferrit
α-Ferrit
+ Perlit
+ Fe3C tertiär
Perlit
+ Fe3C sekundär
Perlit
+ Ledeburit II
+ Fe3C sekundär
Ledeburit II
+ Fe3C primär
α + Fe3C tertiär
Perlit
Ledeburit
Zementit (Fe3C)
A0 230 °C
Q
0,02% C
0,8% C
2,06% C
4,3% C
6,67% C
ferromagnetisch
paramagnetisch
1600
1400
1200
1000
800
600
400
200
20
0
2
4
6
Gew. % C
Stahl
Gusseisen


C°
KOHLENSTOFFGEHALT IN ATOMPROZENT
2,3
3,6
4,5
6,6
Schmelze + δ-Mischkristalle
Schmelze
1493 °C
δ-Mischkristalle
δ-Mischkristalle + Austenit
Schmelze + Austenit
Austenit (γ-Mischkristalle)
Kubisch raumzentriertes Atomgitter
Kubisch flächenzentriertes Atomgitter
Diffusionglühen
Hochglühen
Härten + Normalglühen
Aufkohlen
Austenit + Sekundärzementit
Austenit + Ferrit
769 °C
723 °C
Weichglühen
Rekristallisationsglühen
Spannungsarmglühen
Paramagnetisch
Ferromagnetisch
Anlassen
Ferit
Ferit + Perlit
Perit + Zementit
Erholungsglühen
Ferit (α-Mischkristalle)
Untereutektoidischer Stahl
Übereutektoidischer Stahl
eutektoidischer Stahl
KOHLENSTOFFGEHALT IN GEWICHTSPROZENT
ZEMENTITGEHALT IN GEWICHTSPROZENT
Glühfarben
Gelbweiss
Hellgelb
Gelb
Hellgelbrot
Gelbrot
Gut Hellrot
Hellrot
Hellkirschrot
Kirschrot
Dunkelkirschrot
Dunkelrot
Braunrot
Dunkelbraun
Anlassfarben
Grau
Blaugrau
Hellblau
Kornblumenblau
Violett
Rot
Gebbraun
Strohgelb
Weissgelb

Annealing

- Slow cooling, aiming to approach the equilibrium state

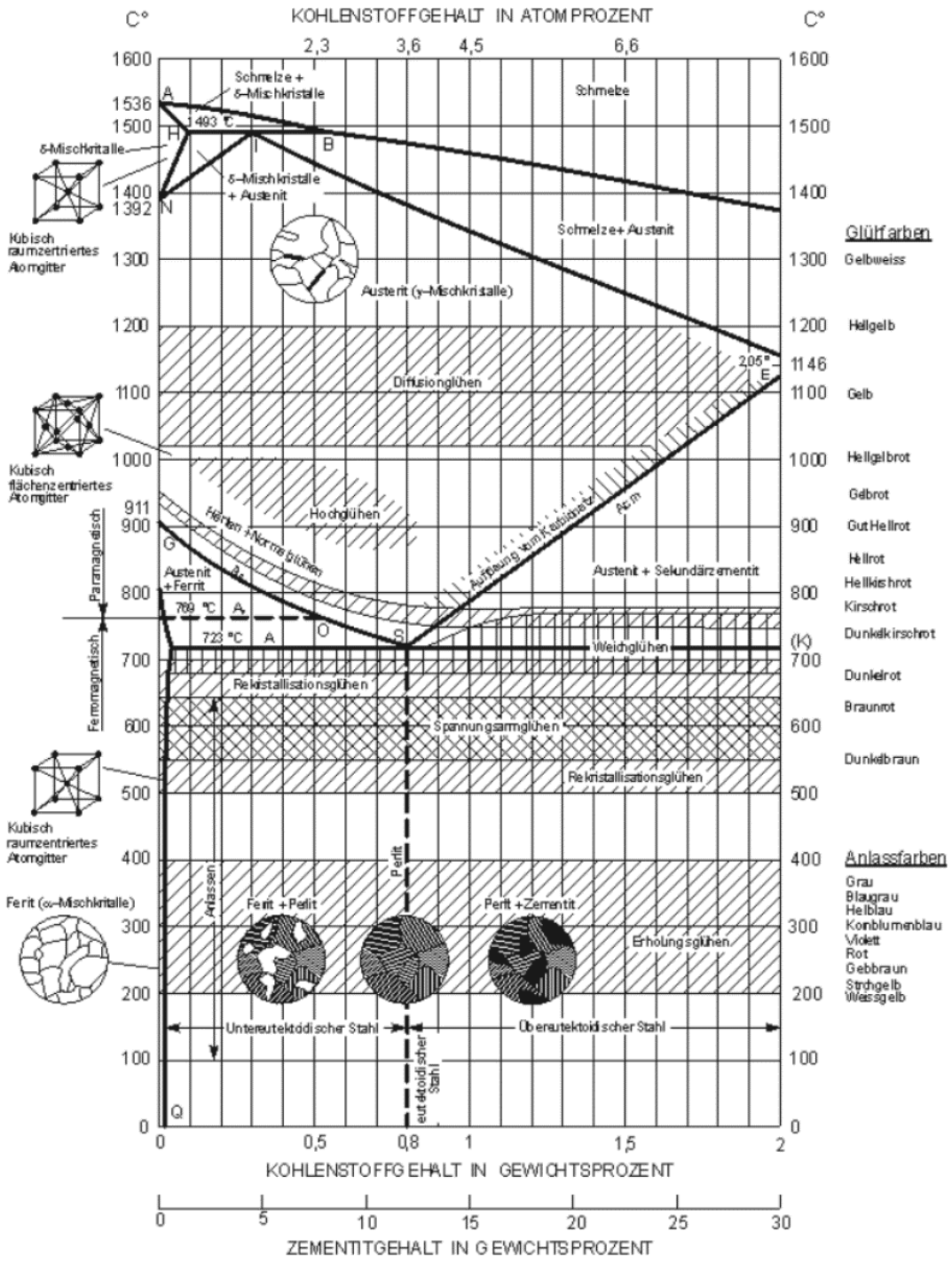
Objectives for:

- Stress-relief annealing
- Recrystallization annealing
- Soft annealing
- Normalizing
- Coarse grain annealing
- Diffusion annealing

Stress-Relief Annealing

- Slow heating to 550 - 650 °C (below A_{c1})
- Holding time 2 - 4 hours, slow cooling (furnace cooling)

Objective:
Reduction of internal stresses (residual stresses) without significant change to other properties



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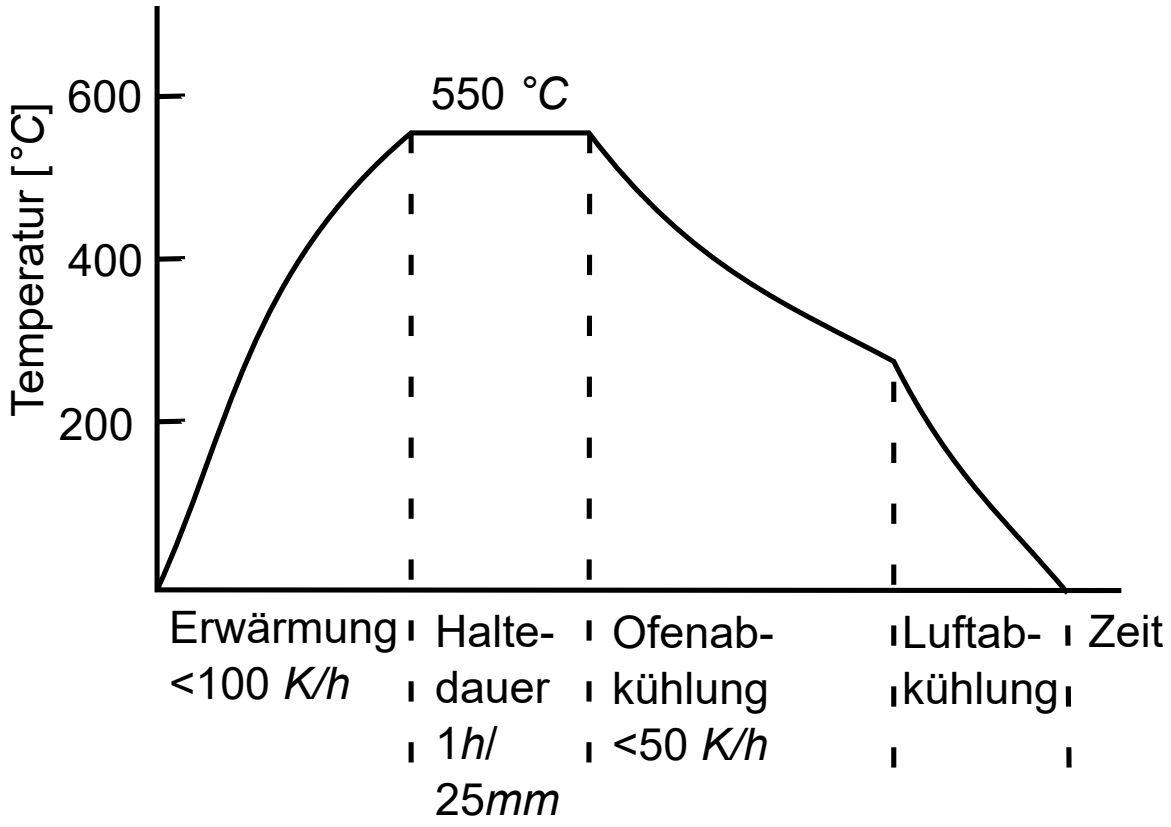
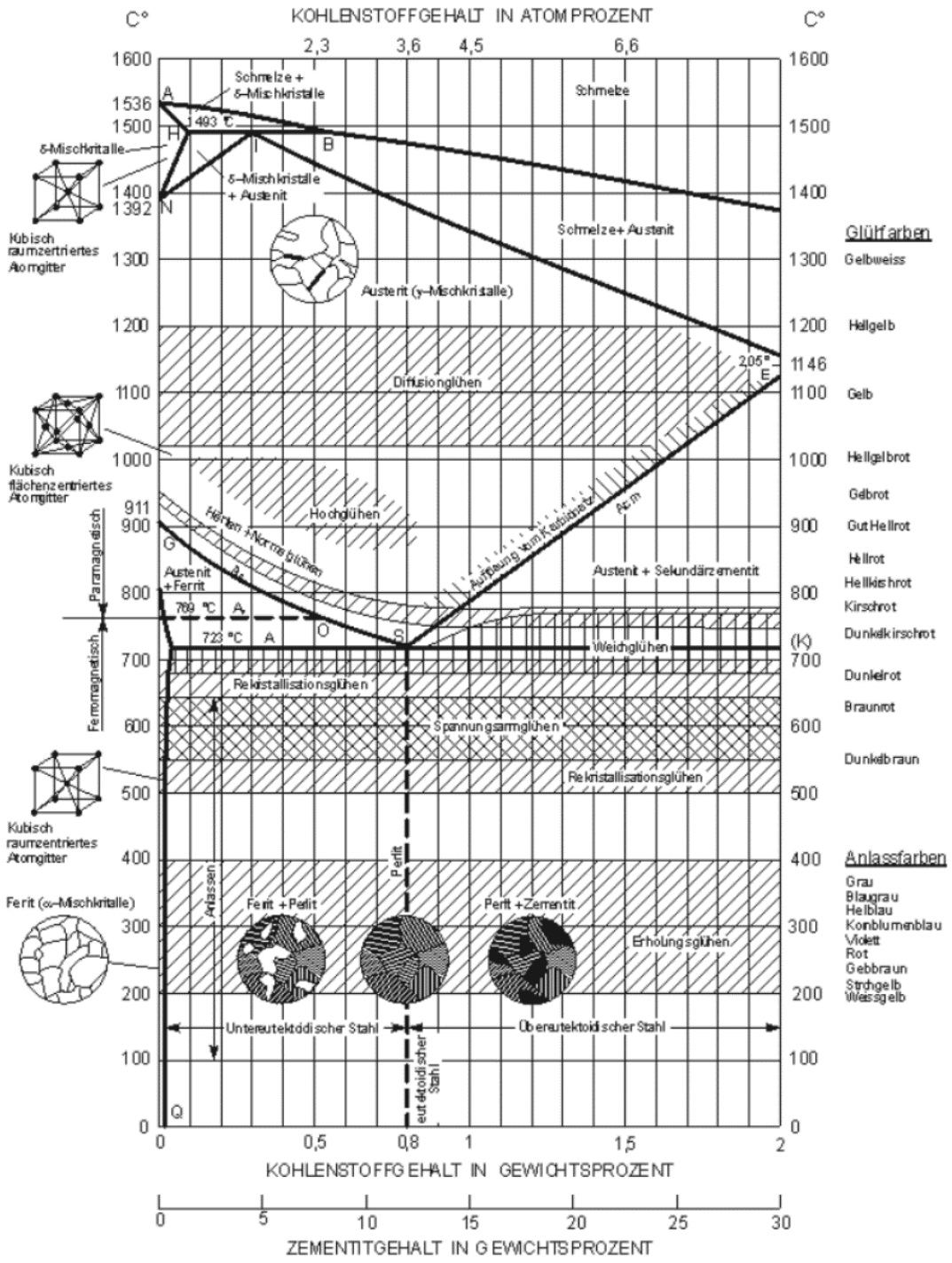


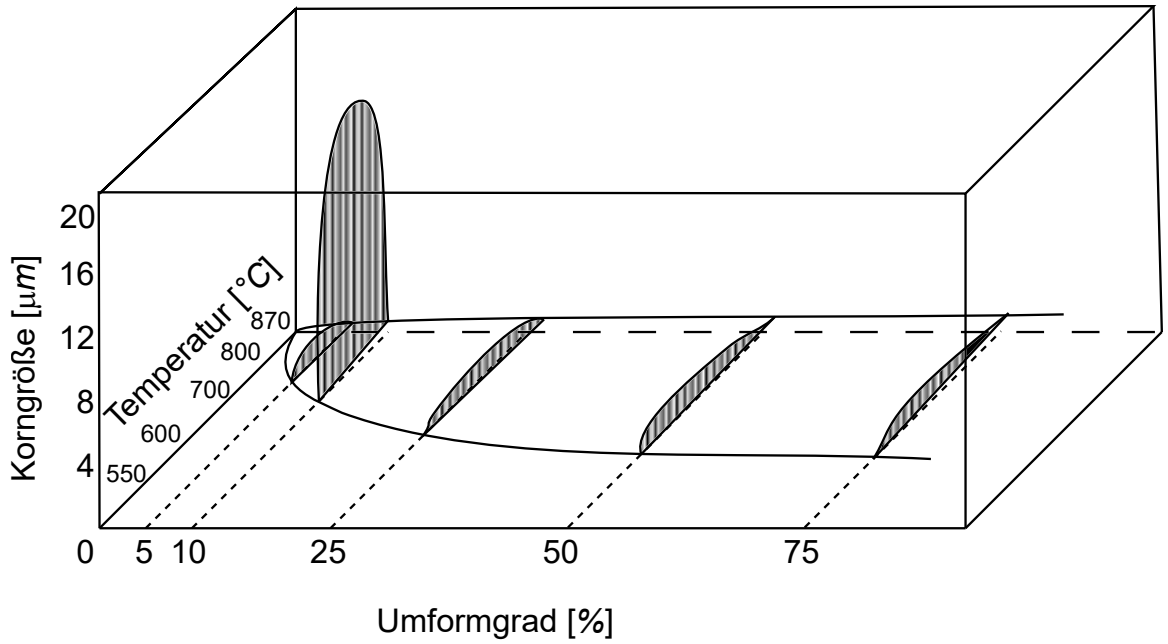
Recrystallization Annealing

- Reversal of property changes (hardening) caused by cold deformation
- Structural transformation or new formation in the solid state
- Stress reduction
- Increase in fracture elongation



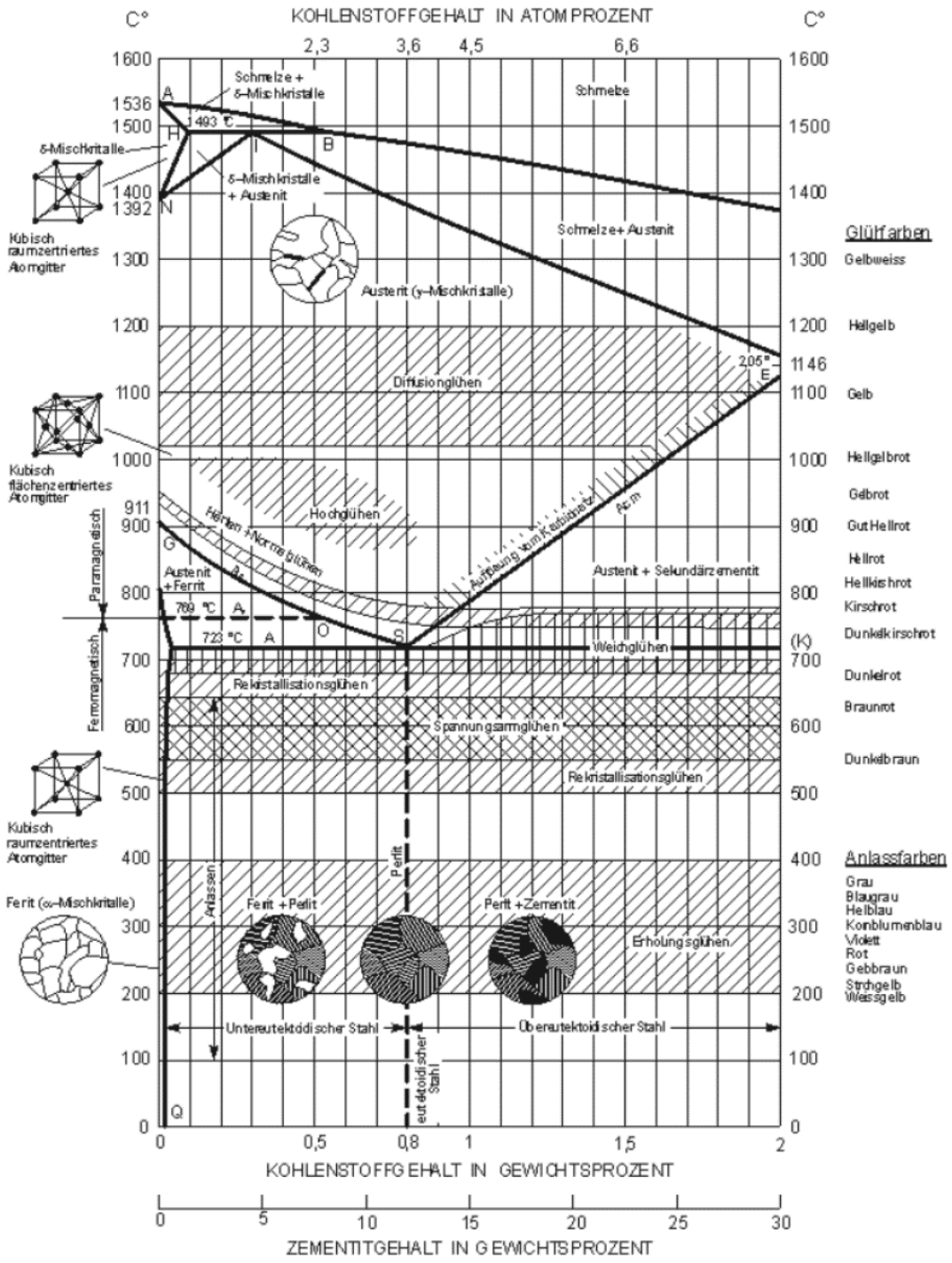
Recrystallization Annealing

- Recrystallization temperature for steel: 500 - 600 °C
- Holding, slow cooling
- Excessive holding time: coarse grain formation



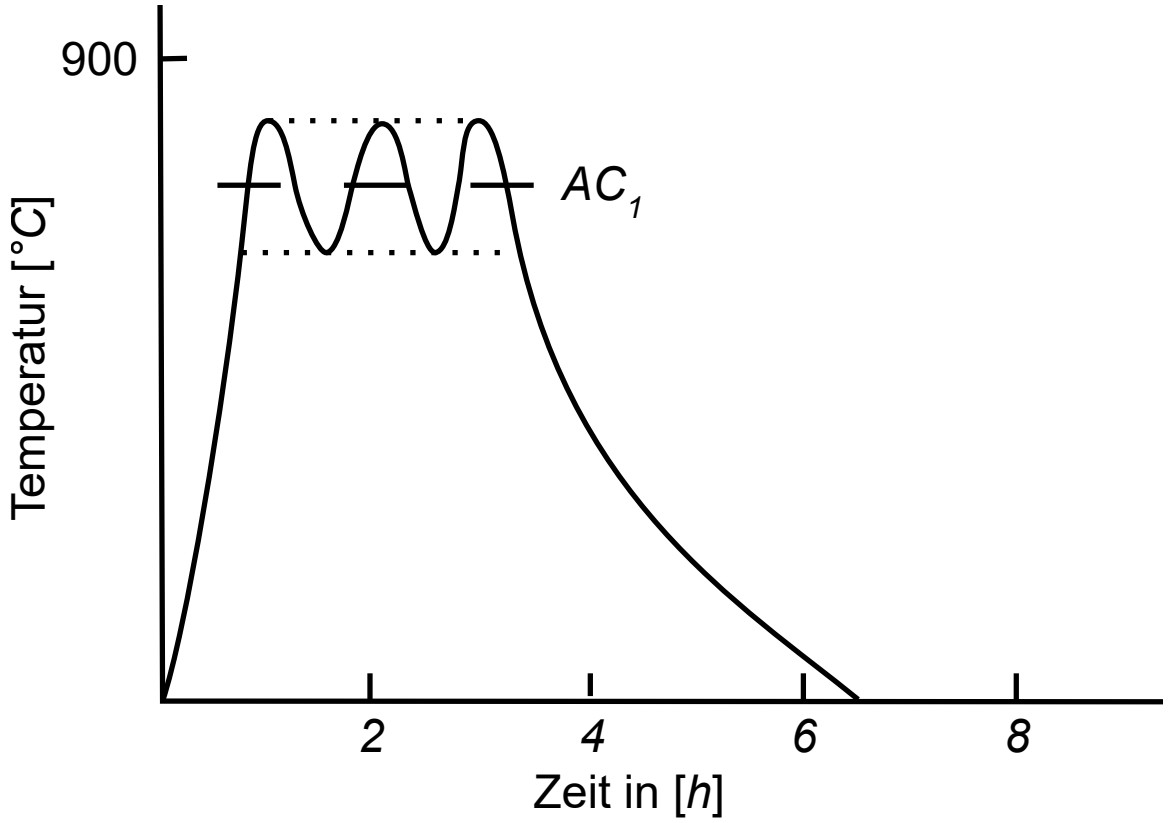
Soft Annealing

- Producing a soft condition favorable for further processing
- Cementite particles are spherodized (spherodized annealing).



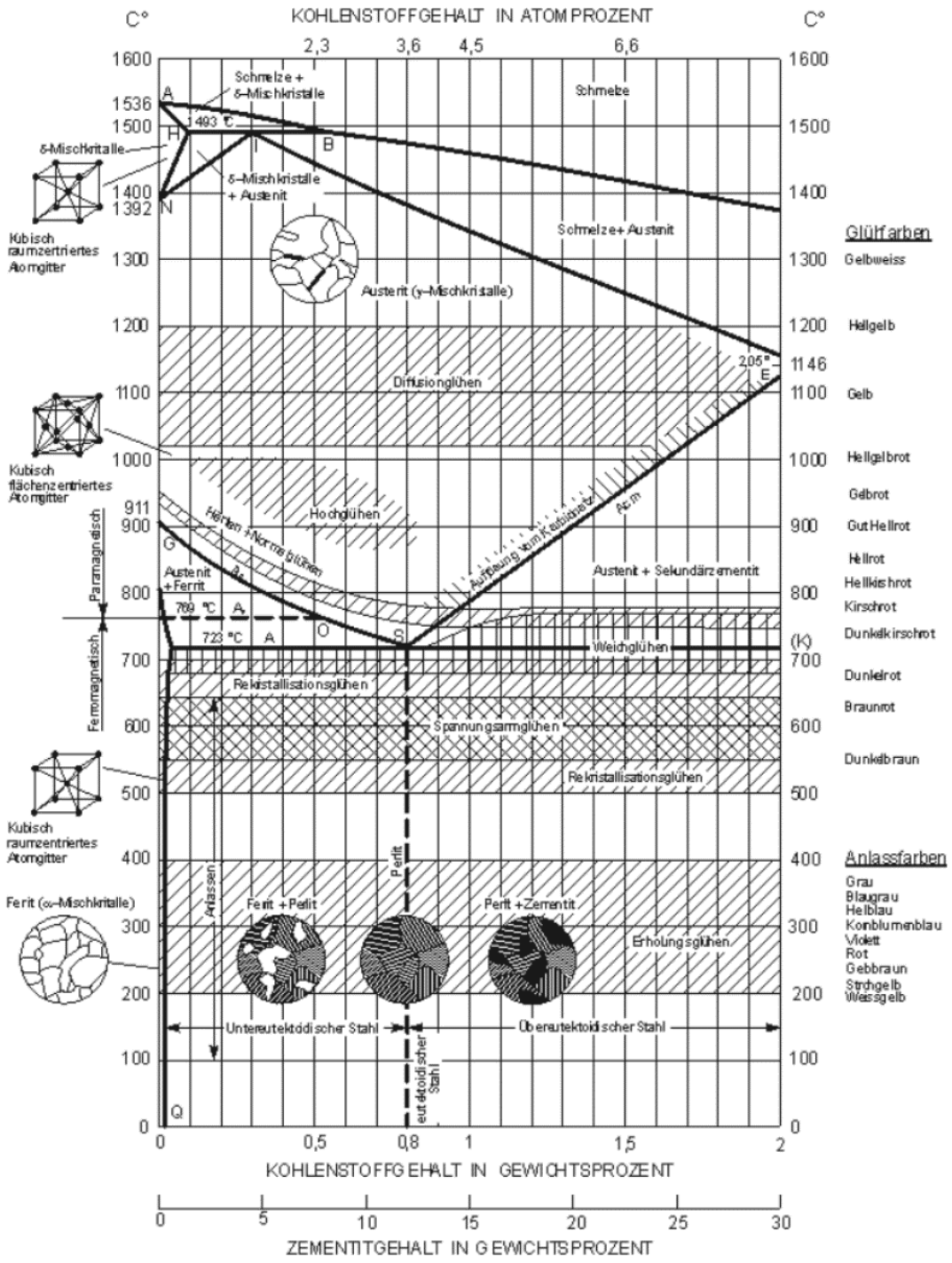
Soft Annealing

- Temperatures around A_{C1} (below, above, or oscillating around A_{C1})
- Slow cooling.



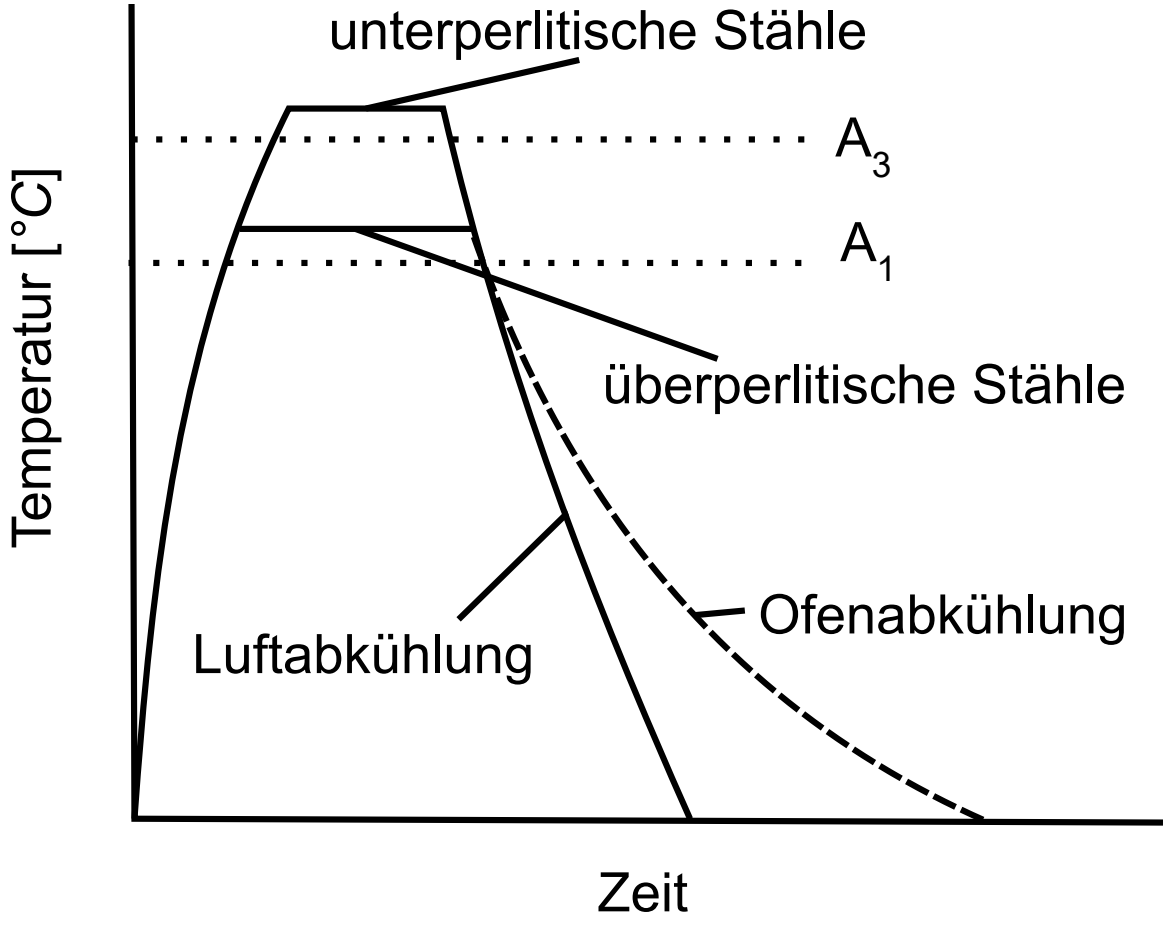
Normalizing

- Temperature 30 - 50 °C above transformation temperature in the austenite range
- Rapid heating between A_{C1} and annealing temperature, short holding time
- Rapid cooling through two-phase interval, then slow cooling



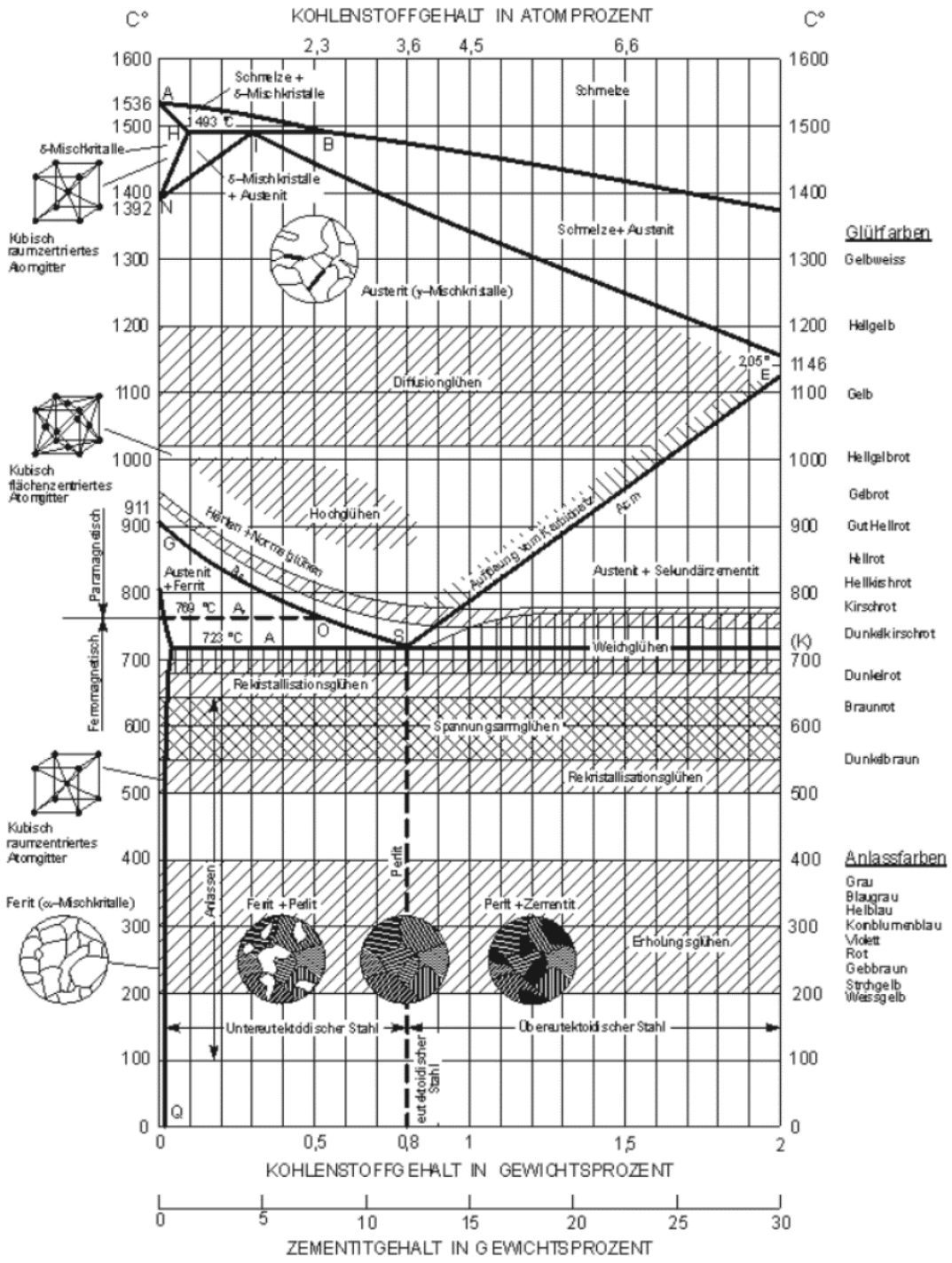
Normalizing

- Produces a uniform, fine-grained structure with pearlite
- Approaches equilibrium state through double recrystallization (during heating and cooling)
- Frequently used process



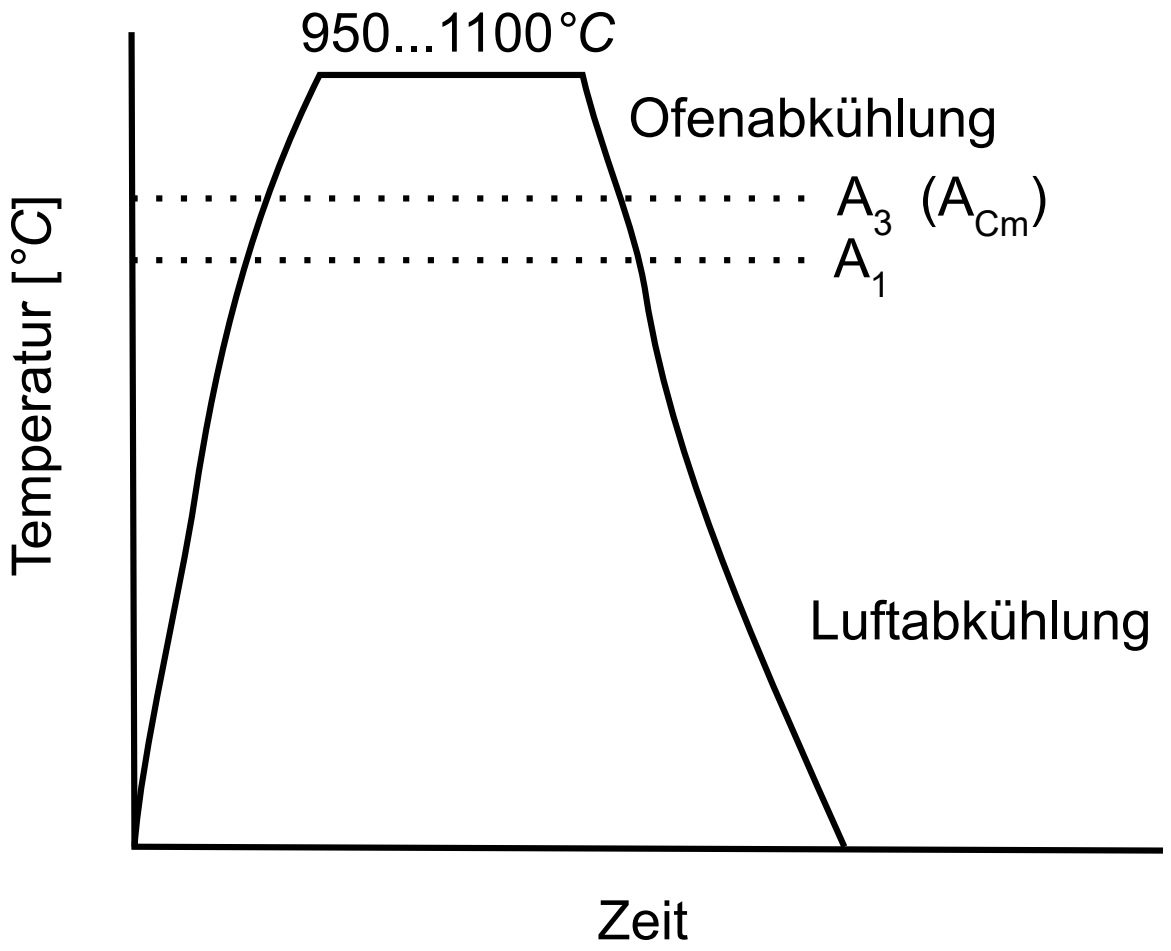
Coarse Grain Annealing

- Achieves coarse grains
- Improves machinability



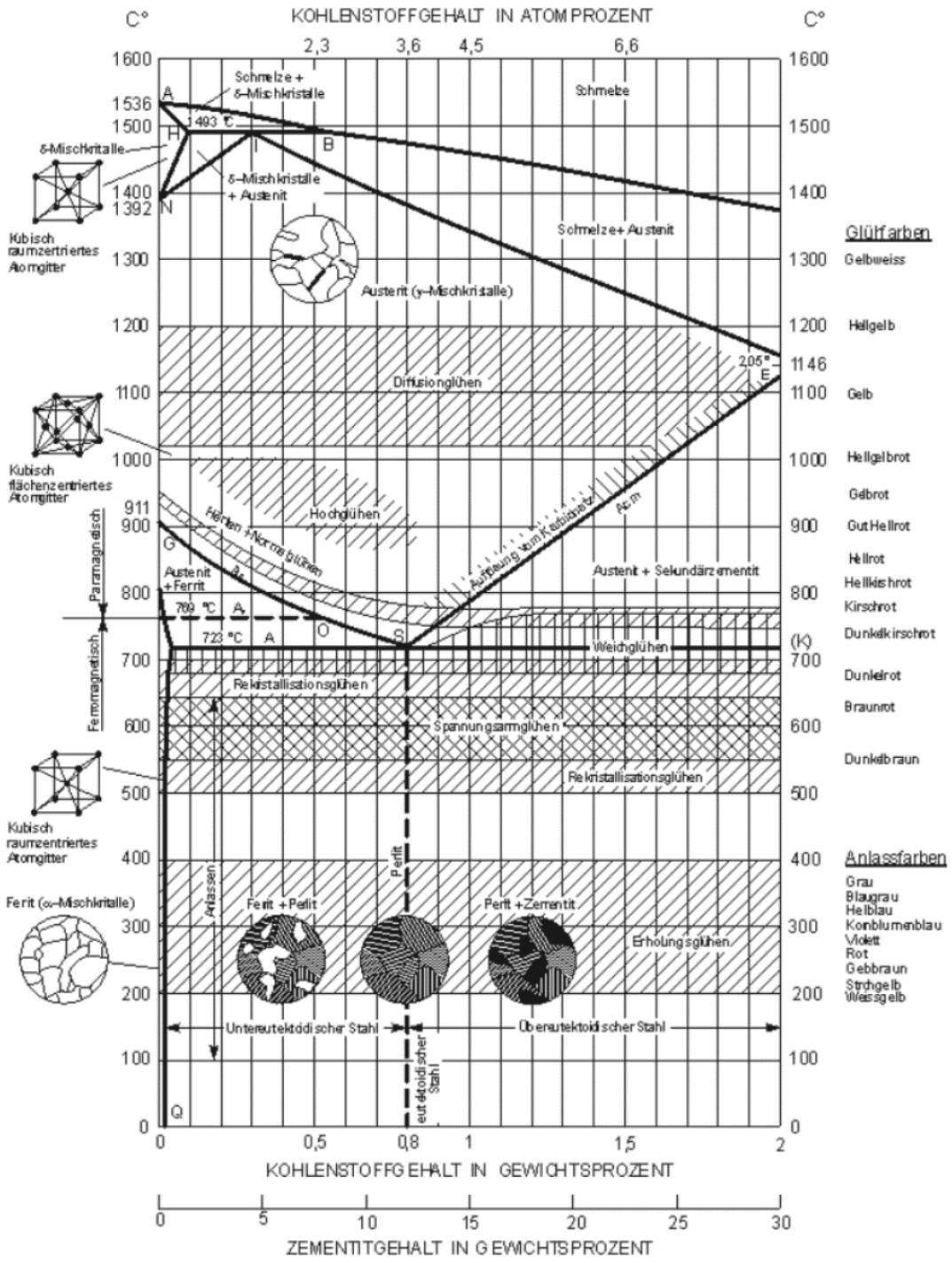
Coarse Grain Annealing

- Temperature significantly above A_{C3} (950 - 1100 °C)
- Holding time 1 to 2 hours
- Slow furnace cooling
- Faster air cooling afterward



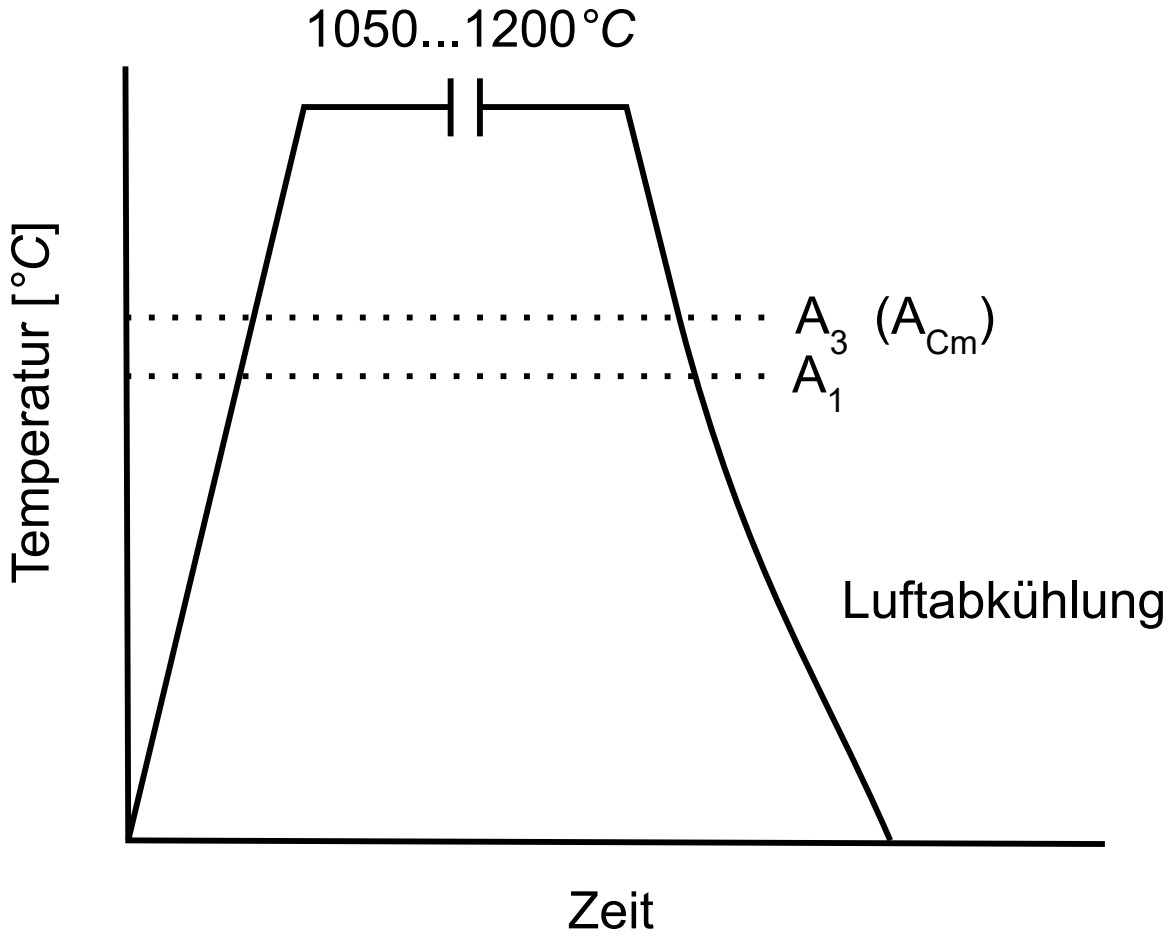
Diffusion Annealing

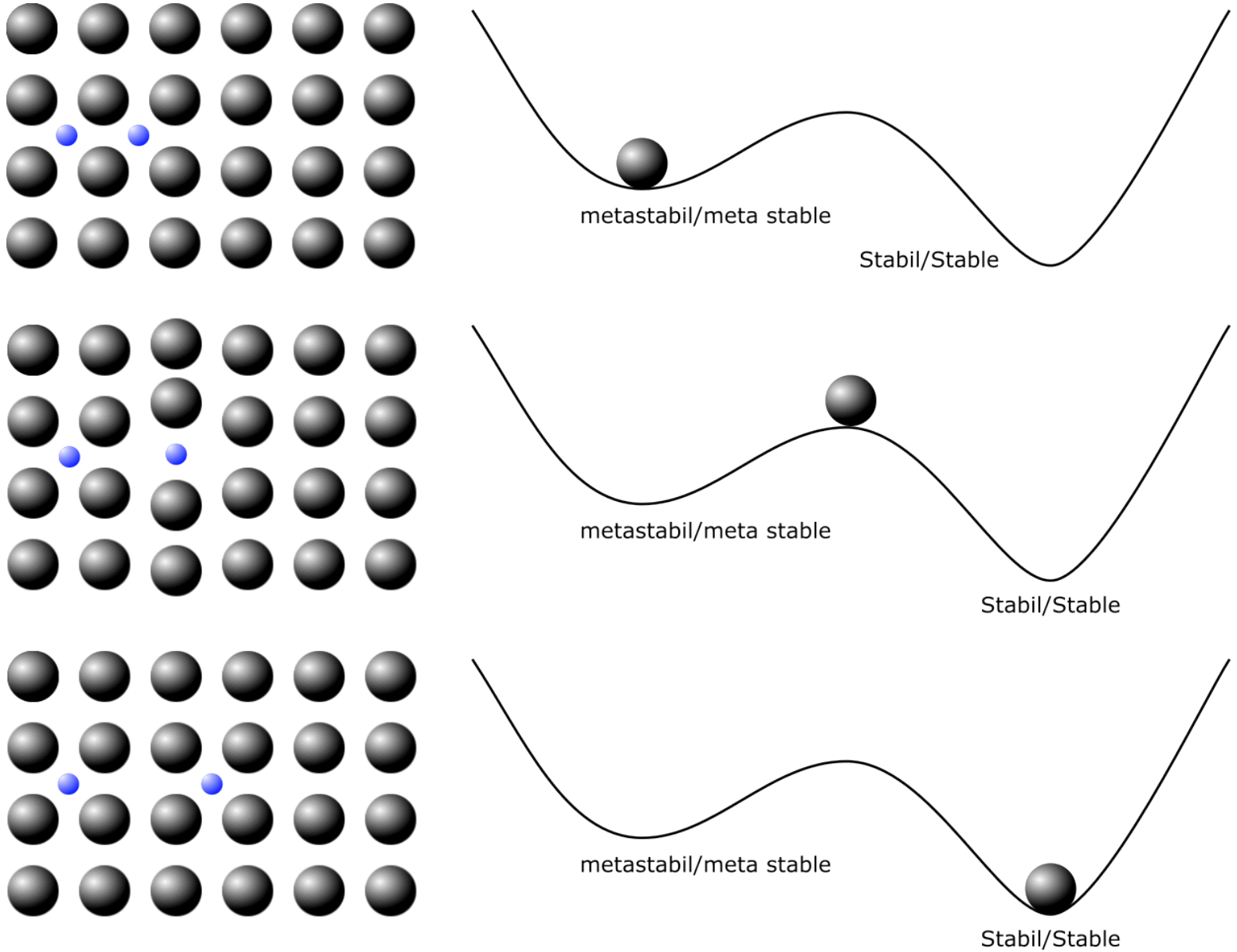
- Eliminates local concentration differences (segregations) through diffusion



Diffusion Annealing

- High temperature in the austenite range
- Long holding time (up to 50 hours)
- Slow cooling




metastabil/meta stable
Stabil/Stable
metastabil/meta stable
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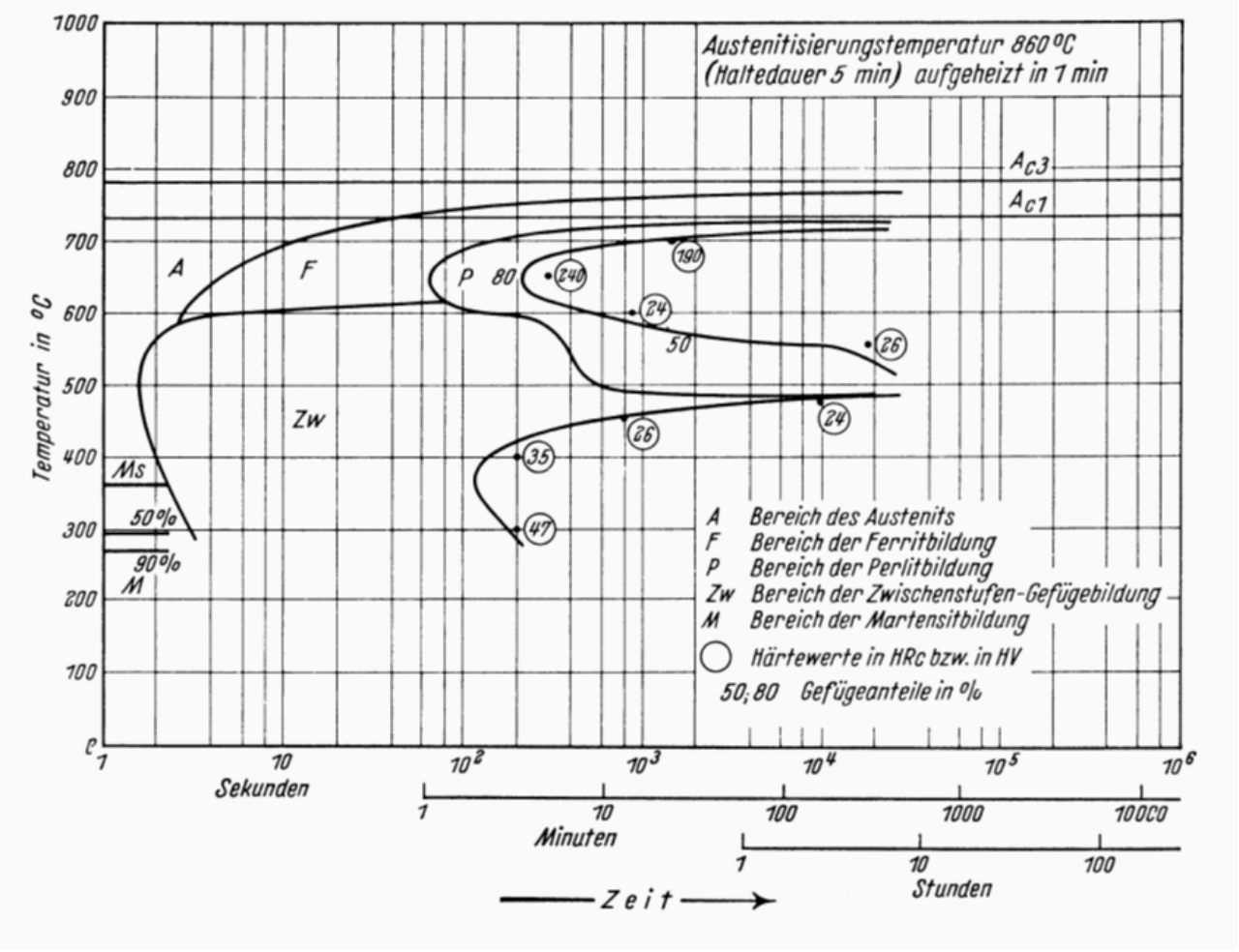
TTT Diagrams

- Time-Temperature-Transformation diagrams
- Provided for various materials and alloys
- Basis for planning heat treatment processes
- Differentiation in cooling at
  - constant temperature (isothermal transformation)
  - continuous cooling

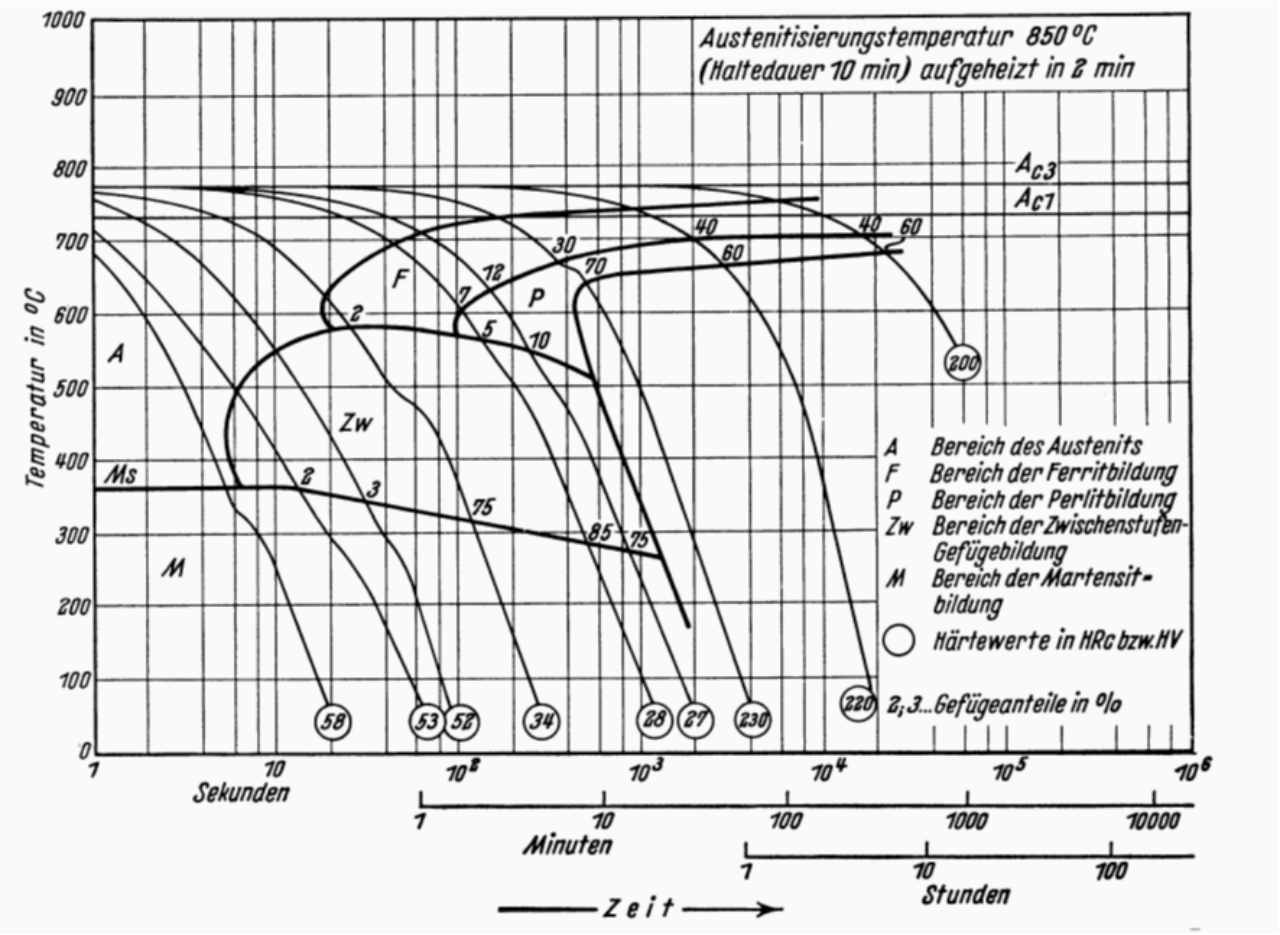
Isothermal Transformation

- Sample is quenched
- Held at constant temperature until transformation is complete



Continuous Cooling

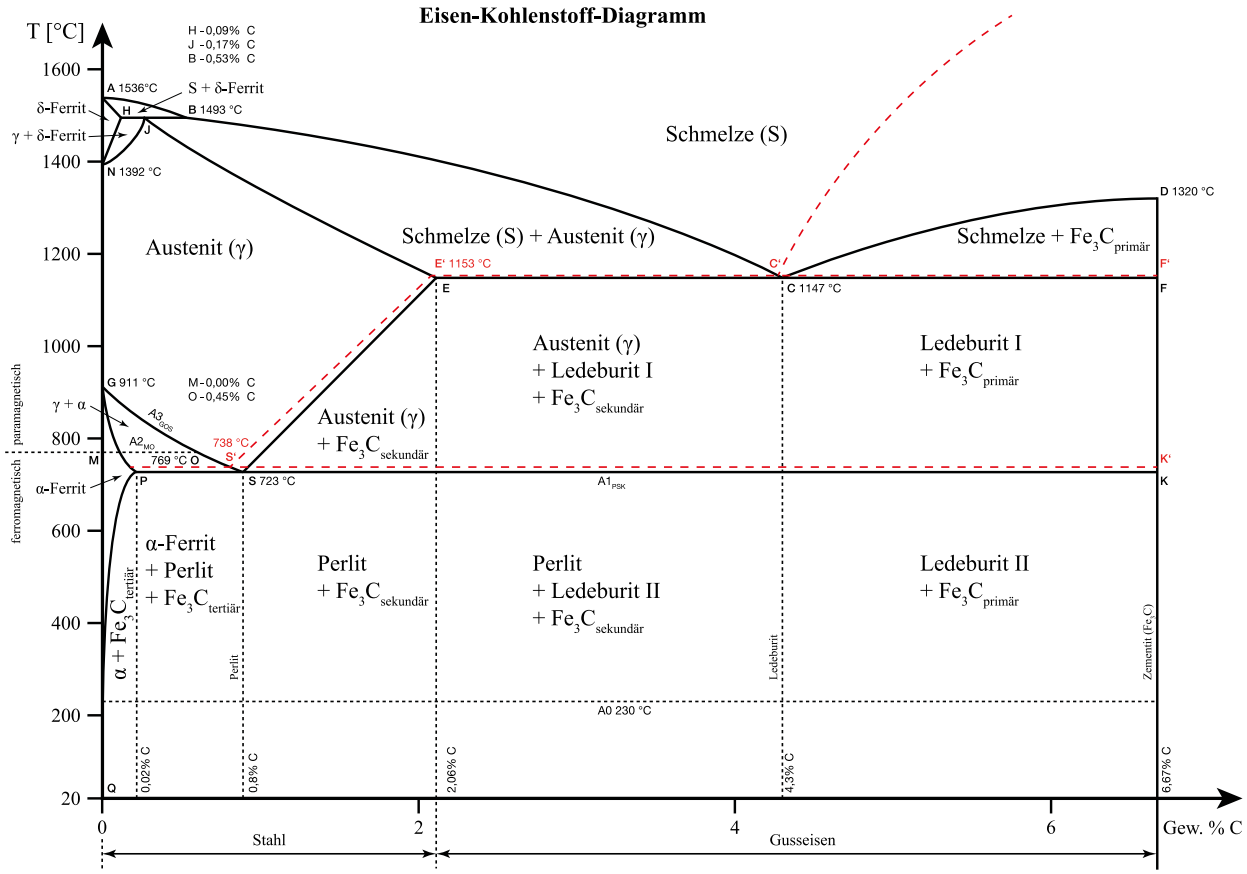
- Starting from the austenitization condition, cooled at various rates
- Transformation into ferrite, pearlite, bainite (intermediate stage), or martensite occurs at different temperatures to varying extents
- Final hardness is usually marked at the end of the cooling curve



Hardening Processes

Hardening

- Cooling from a temperature above the transformation line GOSK at a rate faster than the critical rate (“quenching”)
- Goal is a non-equilibrium state through the transformation of austenite into martensite (possibly bainite)



Processes

- Volume heating hardening
- Tempering
- Quenching and tempering
- Surface hardening
- Thermochemical processes
  - Carburizing / case hardening
  - Nitriding
- Thermomechanical processes
- Curing

Volume Heating Hardening

- Carbon content of at least 0.3% (otherwise pre-treatment required)
- For small cross-sections, complete martensite formation can occur throughout the section (through-hardening). For large sections, the critical cooling rate is achieved only up to a certain depth (case hardening).
- Maximum hardness depends only on carbon content

Surface Hardening

- Applied to low-alloy and unalloyed steels with 0.3 - 0.7% carbon (upper limit to avoid quench cracks)
- Especially for crankshafts, journals, rolls, gears, etc. The goal is a hard and wear-resistant surface with a tough core.
- Surface layer of the workpiece is heated to hardening temperature and quenched to harden.

Methods

The surface hardening can be achieved through the following methods:

- Flame hardening
- Induction hardening
- Beam hardening (electron beam and laser hardening)
- Quenching