International Welding Engineer (IWE)

Module 2: Materials and Their Behavior During Welding

2.3 - Iron-Carbon Alloys

March 2018- Tehran-IWREC

Lecturer : Kamran Khodaparasti

References

- References:
  - SLV Software
  - Internet documents

2.3 Iron-Carbon Alloys

Objective:

Understand/name the principles of alloying iron with carbon, the crystalline structures developed under equilibrium and non-equilibrium conditions and their representation in phase and transformation diagrams.

Scope:

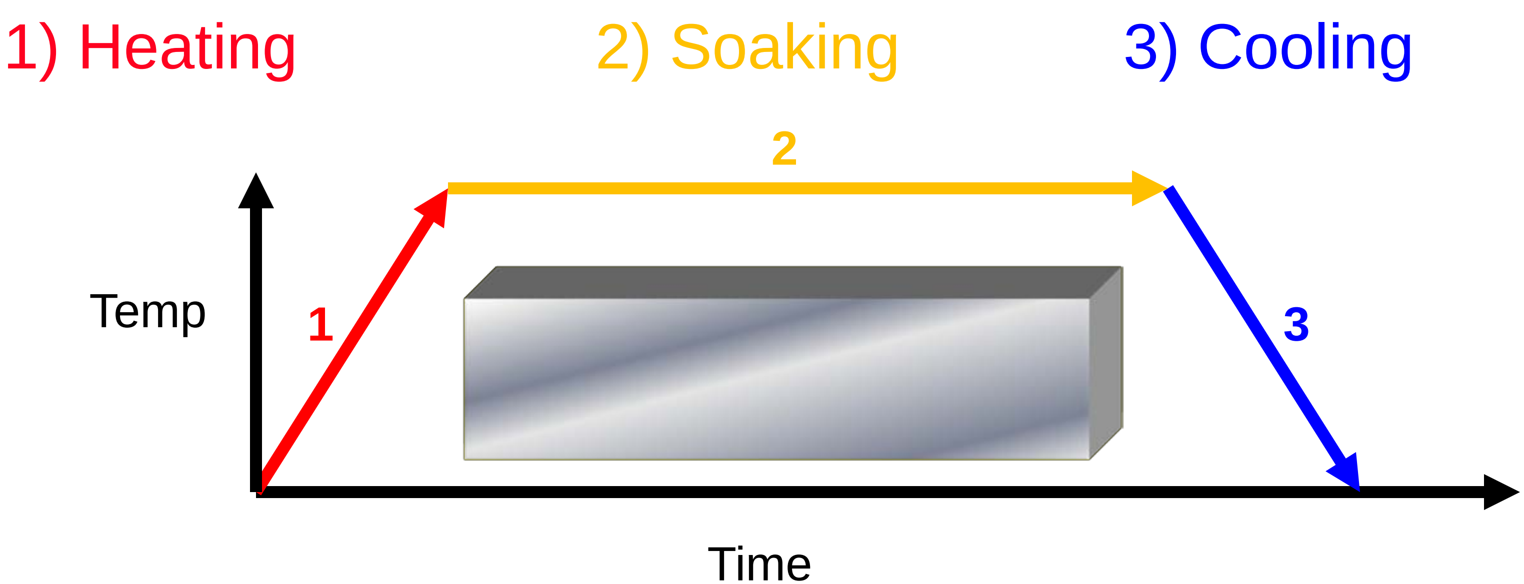
- Equilibrium and non equilibrium transformations
- Time-temperature-transformation (TTT) diagrams
- Different types of TTT diagrams (isothermal, continuous cooling, TTT diagrams for welding)
- Influence of alloying elements
- Carbide forming elements
- Control of toughness
- T8/5 concept

Expected Result

- Interpret the reasons for different structures under equilibrium and non-equilibrium conditions.
- Explain the use of TTT diagrams (isothermal, continuous cooling, TTT diagrams for welding) to show the development of particular steel microstructures.
- Predict the changes that strengthen structure caused by alloying additions with reference to TTT diagrams.
- Detail hardening mechanisms with reference to the microstructure developed.
- Interpret the relationship between microstructure and toughness.

Introduction

- During manufacturing up to the final product, steels are heated and cooled again, in some cases more than once.
- The different types of thermal treatments can be described by a temperature cycle consisting of heating, keeping at that temperature (soaking), and cooling.

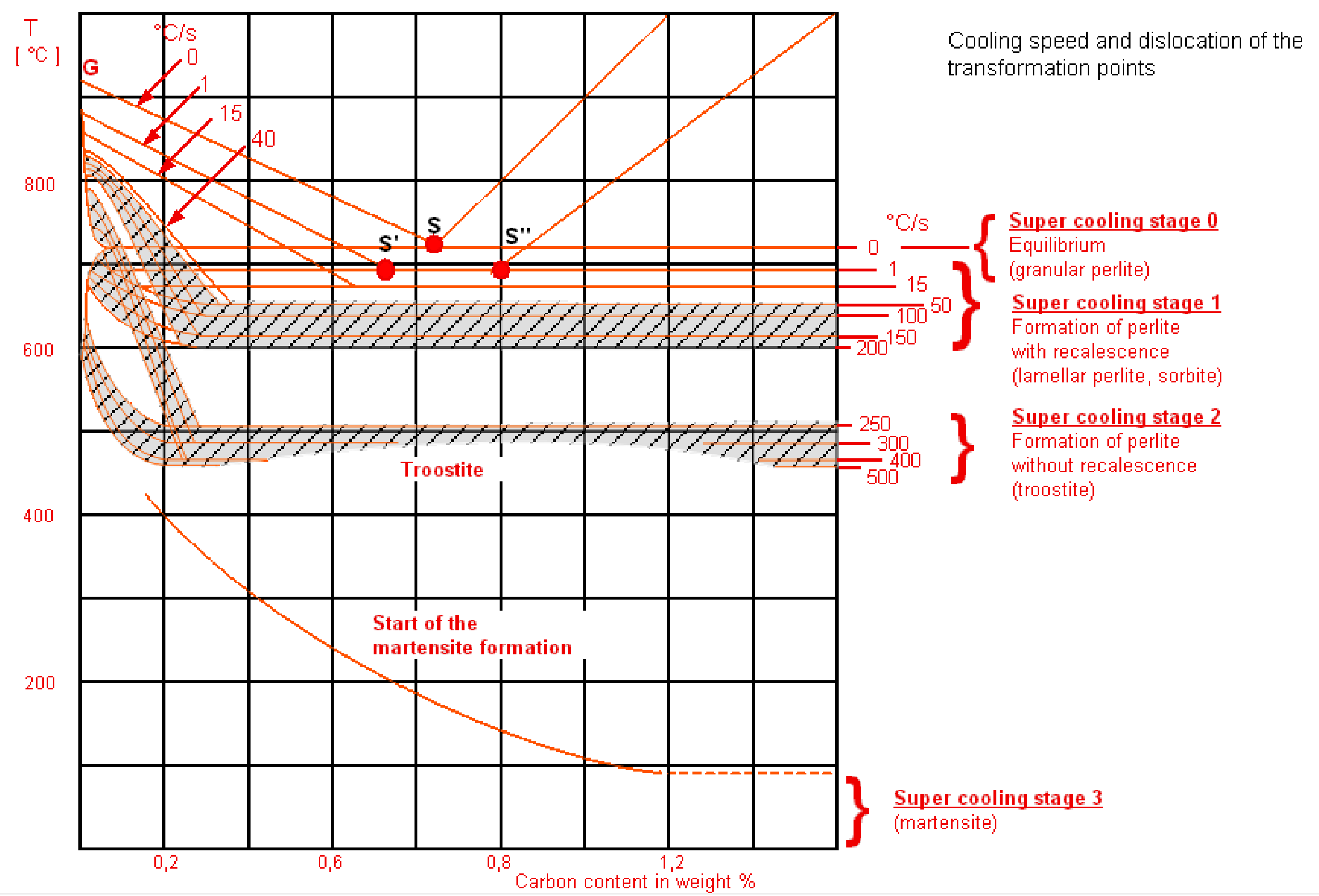


Introduction

- In equilibrium condition the ferrite and pearlite can be achieved
- For getting certain mechanical properties (higher strength and toughness) non equilibrium transformation is used
- For this purpose higher cooling rates are used
- If the cooling rate is rapid enough, the temperature of transformation of austenite to ferrite and pearlite is decreased

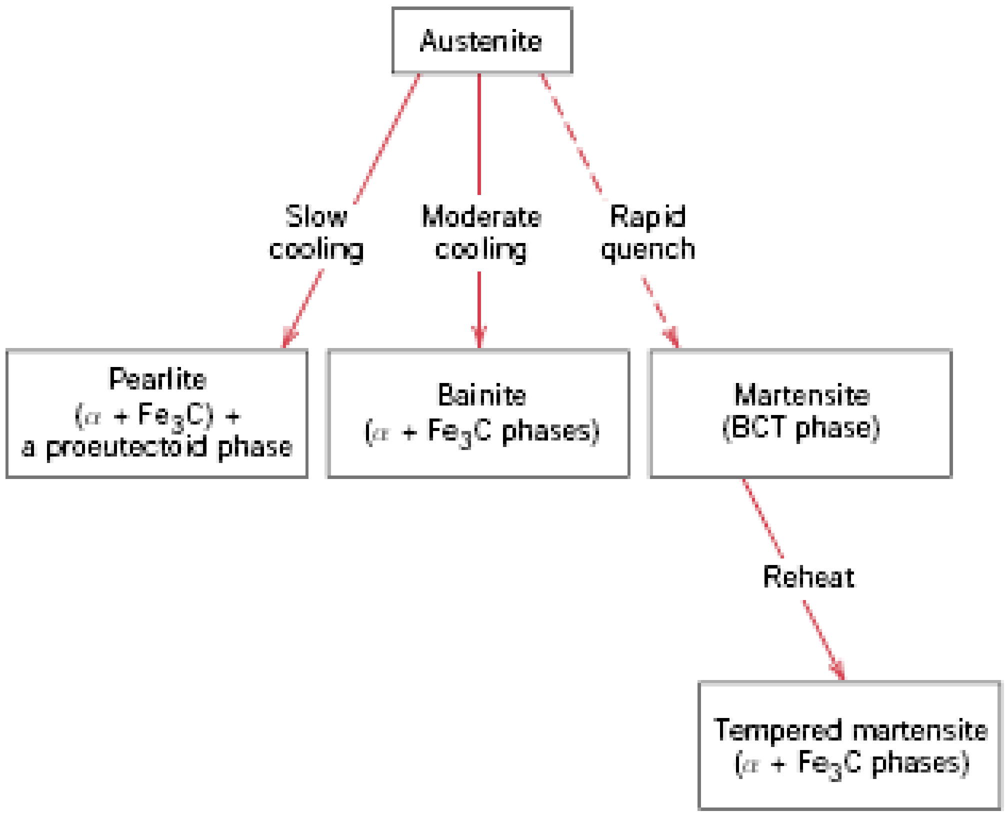
Cooling Speed and Shift of the Transformation Points

- The iron carbon diagram is a diagram of equilibrium, i.e. the lines and transformations are valid for “infinitely” slow cooling. Depending on the cooling speed cooling leads to a shift of the points in the iron carbon diagram



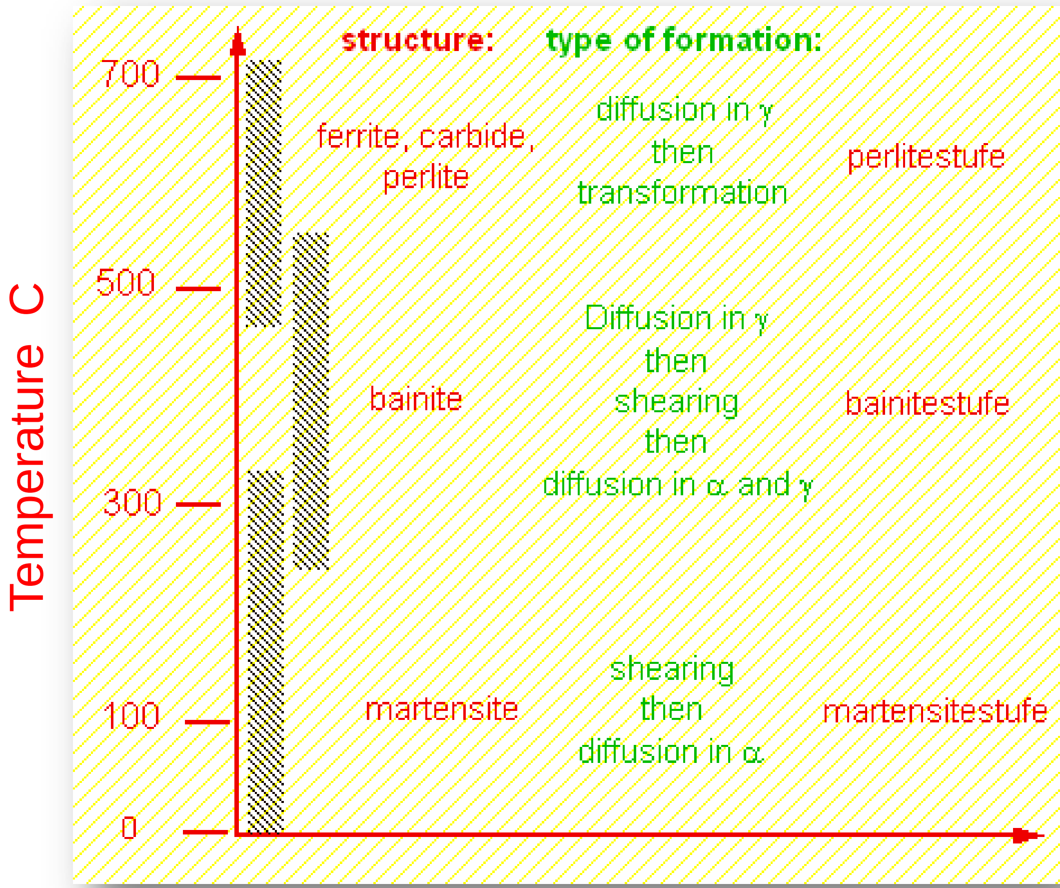
Structure of the Same Steel at Different Cooling Speed

- With some thermal treatments such as normalizing and hardening it will be heated to a given austenitizing temperature and after keeping at this temperature it will be cooled again. The structure obtained by cooling depends on the cooling speed



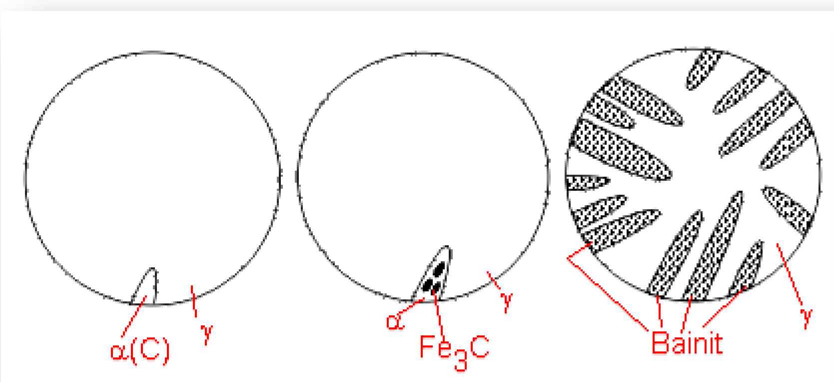
The Structures Dependence

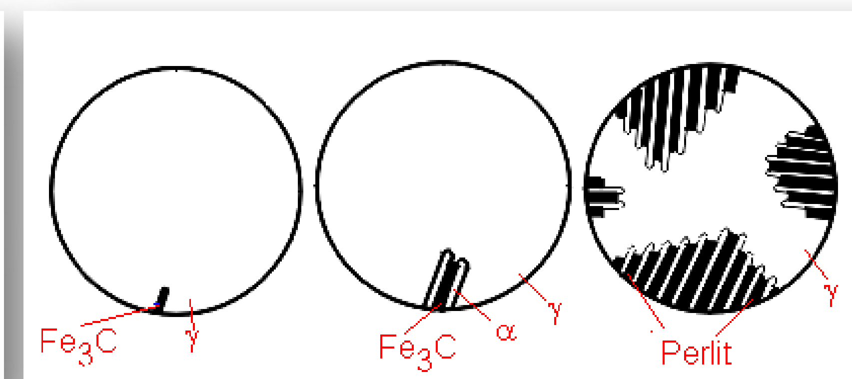
- Dimensions of the temperature ranges as well as mechanisms during the formation of the most important structure in unalloyed steels



Classification into Three Groups

- Pearlite stage: At high temperatures both, the carbon and the alloying elements are able to diffuse during the transformation process, i.e. a diffusion controlled change of the concentration at the / phase boundary takes place over long distances.
- Martensite stage: At a very fast cooling and deep temperatures the atoms cannot diffuse in the time available. At the / phase boundary there will be formed martensite by a "sudden" shearing of the austenite lattice and a cooperative shearing motion of the atoms. In doing so, no equalization of the concentration in the -mixed crystals enriched with carbon will take place.
- Bainite stage: The bainite stage I
- s formed by both, microdiffusion of individual atoms at the phase boundary and by martensitic lattice shearing.

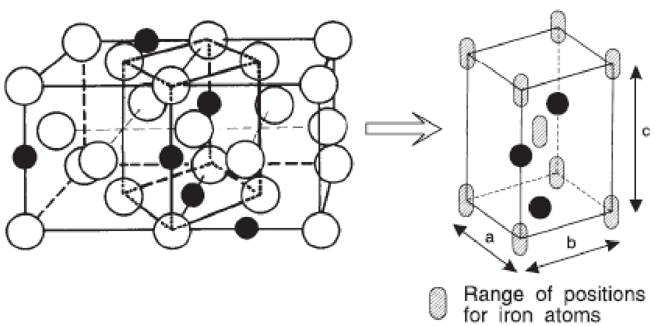




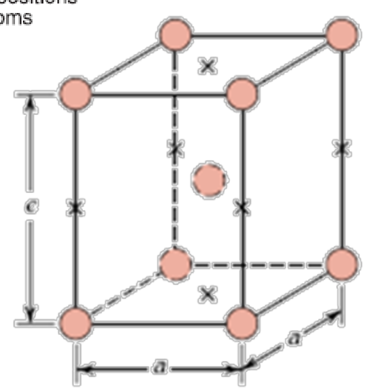
Formation of Martensite

- Diffusionless
- Transformation from austenite (FCC) to ferrite (BCC), the carbon trapped
- Tetragonal distortion of bcc-lattice of ferrite (BCT)
- Very hard and brittle
- Increasing in volume, causes internal stress and cracking

Let's see a clip

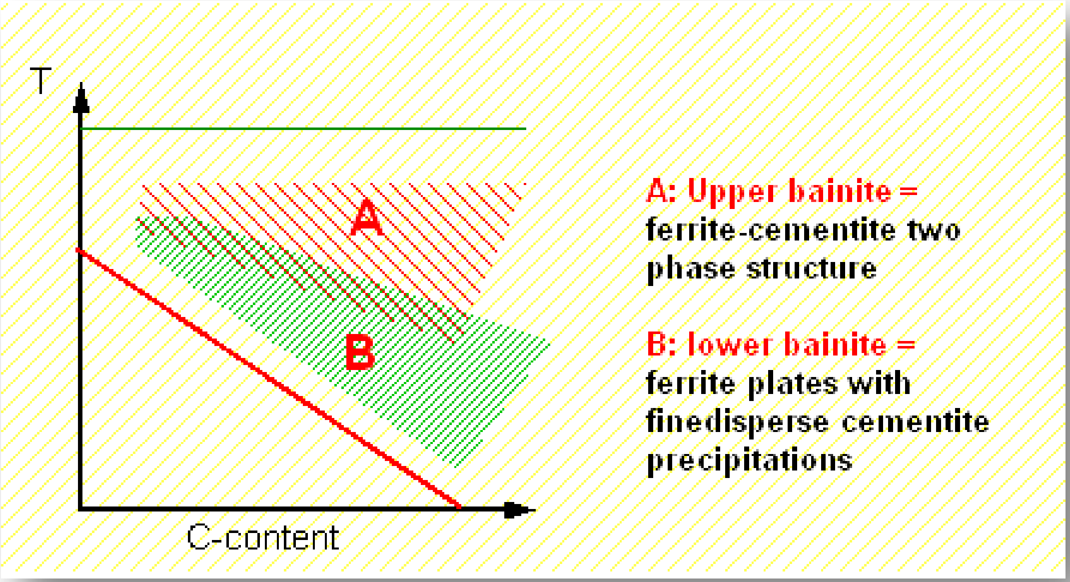


The body-centered tetragonal unit cell for martensitic steel showing iron atoms (circles) and sites that may be occupied by carbon atoms (crosses). For this tetragonal unit cell, c > a.



Bainite

- Depending on the formation temperature and the carbon content it is distinguished between the bainite types upper bainite and lower bainite.
- The upper bainite is generated at higher temperatures than the lower bainite and consists of ferrite lancettes with relatively fine cementite precipitations.
- The lower bainite consists of ferrite lancettes, too, but the cementite in the lancette has been precipitated in the finest shape.

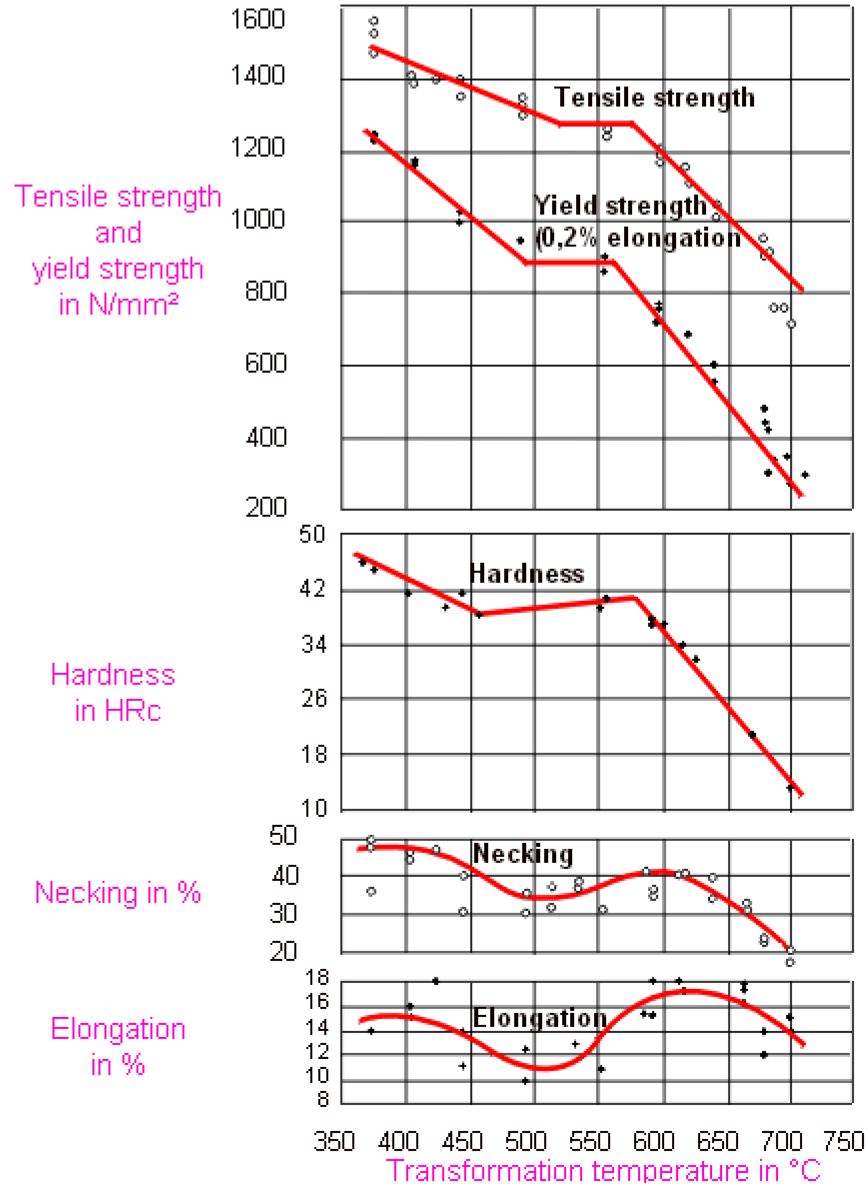


upper bainite=feathery bainite
lower bainite= acicular bainite

Let's see a clip

Dependence of the Mechanical Properties

- The mechanical properties of a steel depend on the transformation temperature at which the austenite transformation into the pearlite, bainite, or martensite stage takes place.



Dependence of the mechanical properties of an unalloyed steel with 0.78 %C, 0.18 % Si and 0.63 % Mn on the transformation temperature. Grain size ASTM 8-9.

IT / TTT

- All diagram we have looked at to this point have been one dimensional phase diagrams. They have been a snapshot based on percent carbon and temperature. We have been looking at phase states as if a vertical line were drawn, depending on the carbon content.
- What happens if we were to increase or decrease the cooling at different rates?
- The result is IT / TTT diagrams.

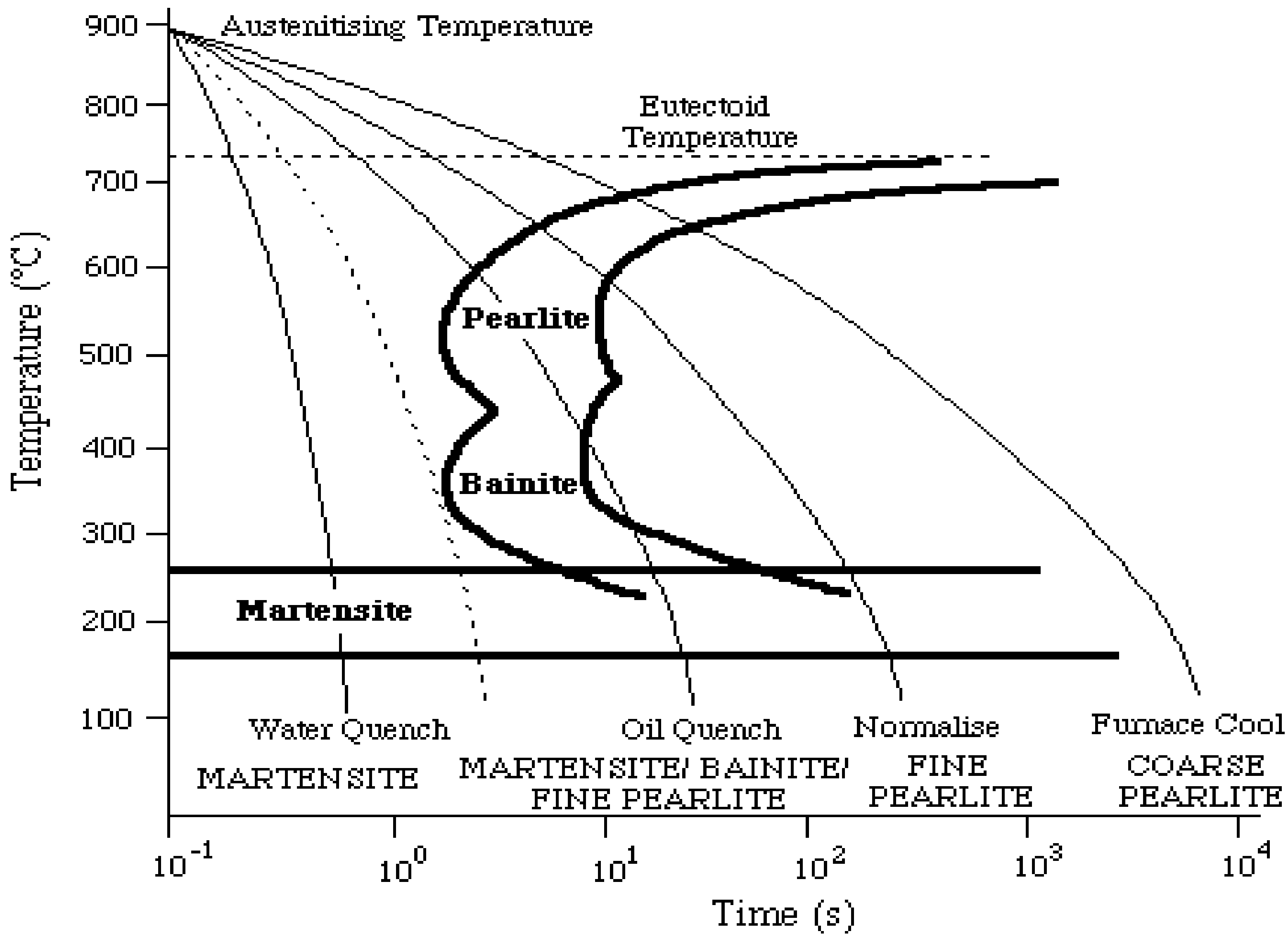
TTT = Time Temperature Transformation Diagrams

IT = Isothermal Transformation

Y Axis = Temperature

X Axis = Time

TTT Diagram for a Eutectoid Steel ($Fe\text{-}Fe_3C$)



Full TTT Diagram

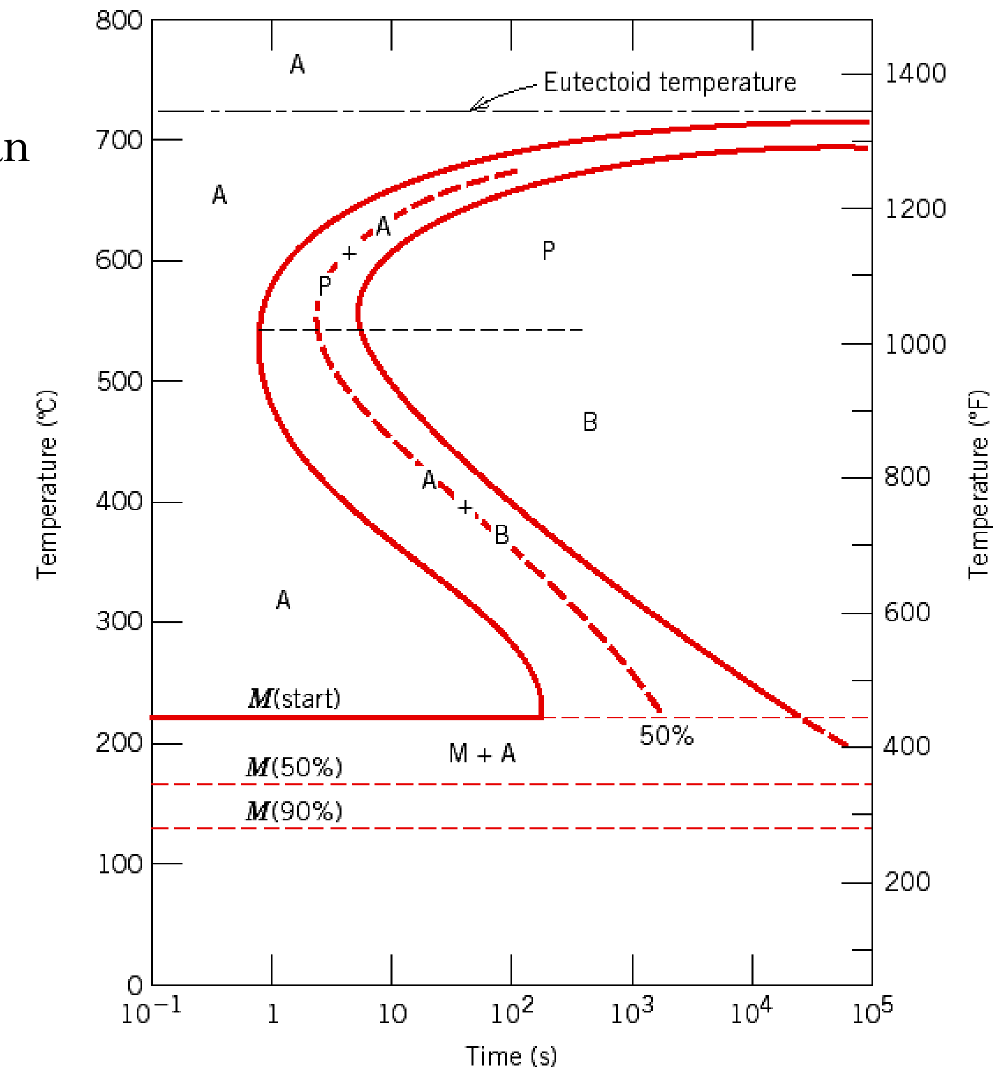
The complete TTT diagram for an iron-carbon alloy of eutectoid composition.

A: austenite

B: bainite

M: martensite

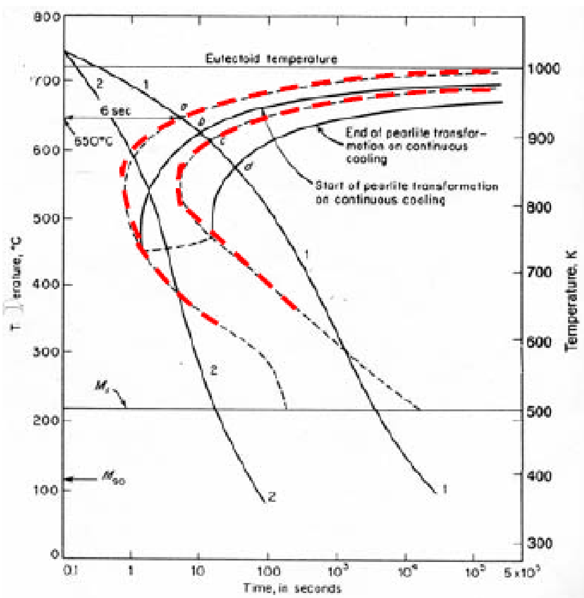
P: pearlite



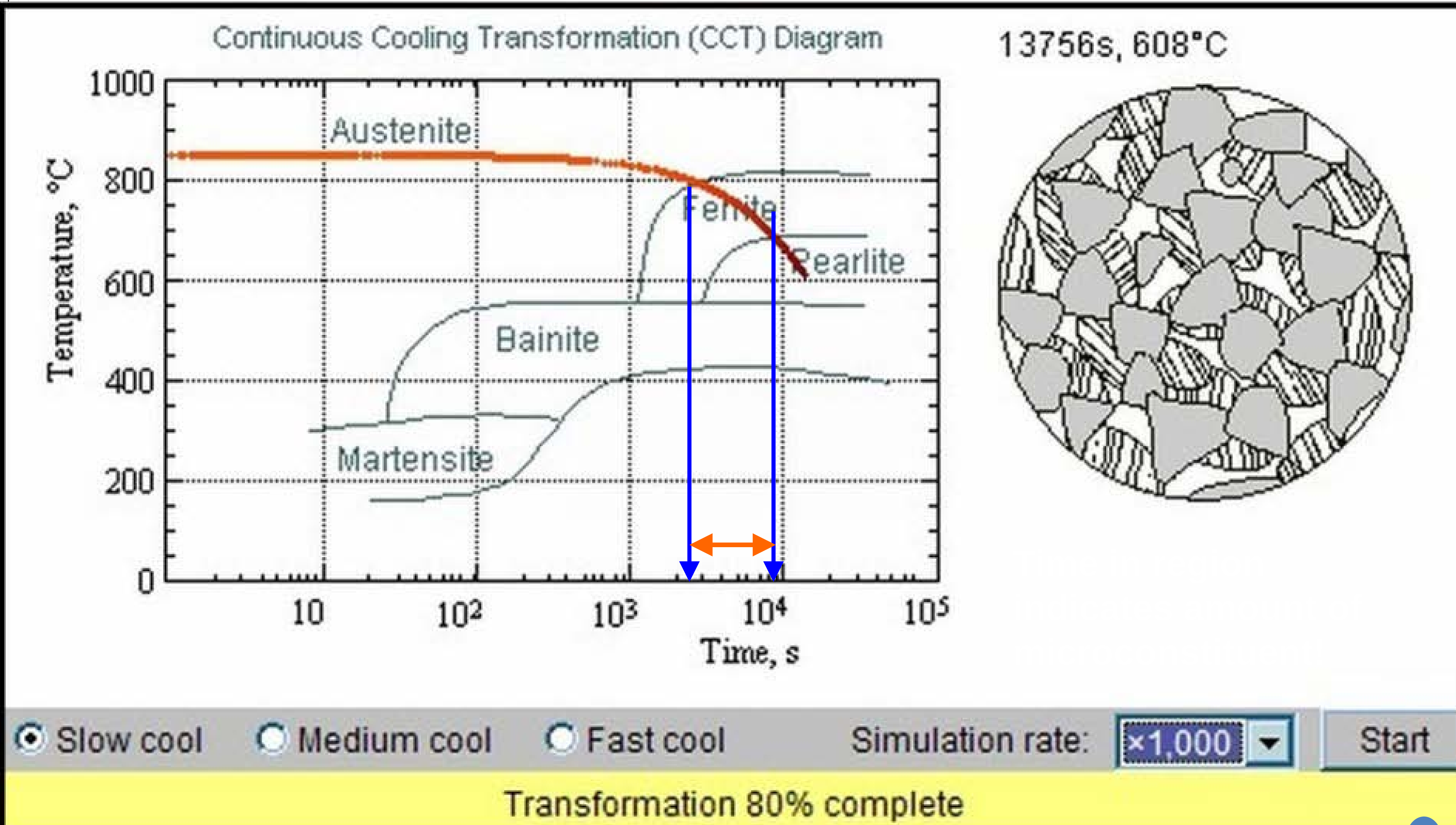
So What's a CCT Diagram?

- Phase transformations and production of microconstituents takes TIME.
- If you don't hold at one temperature and allow time to change, you are "Continuously Cooling".
- Therefore, a CCT diagram's transition lines will be different than a TTT diagram.
- CCT curves are More practical in heat treatment and welding

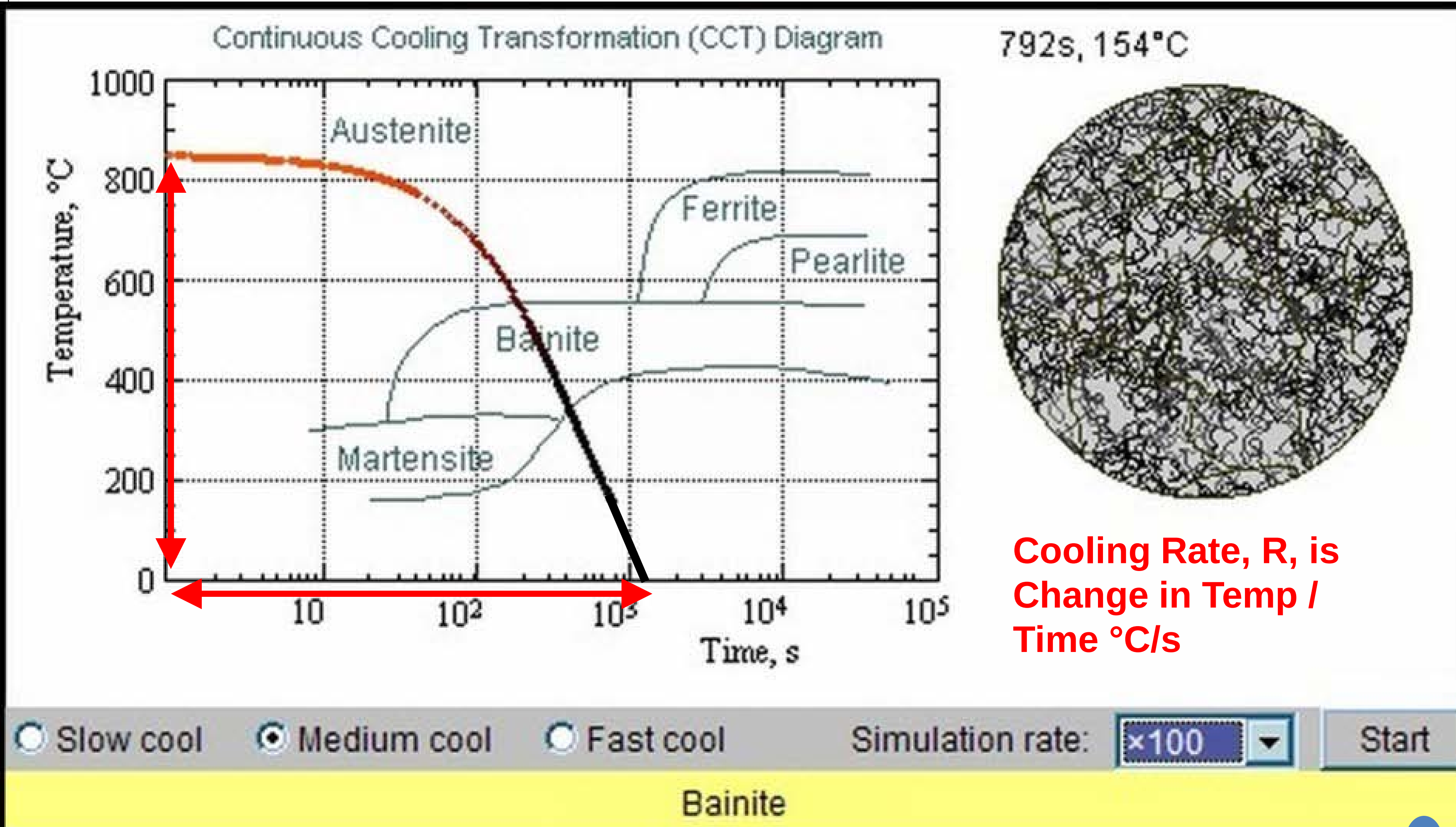
TTT to CCT curve



Slow Cooling

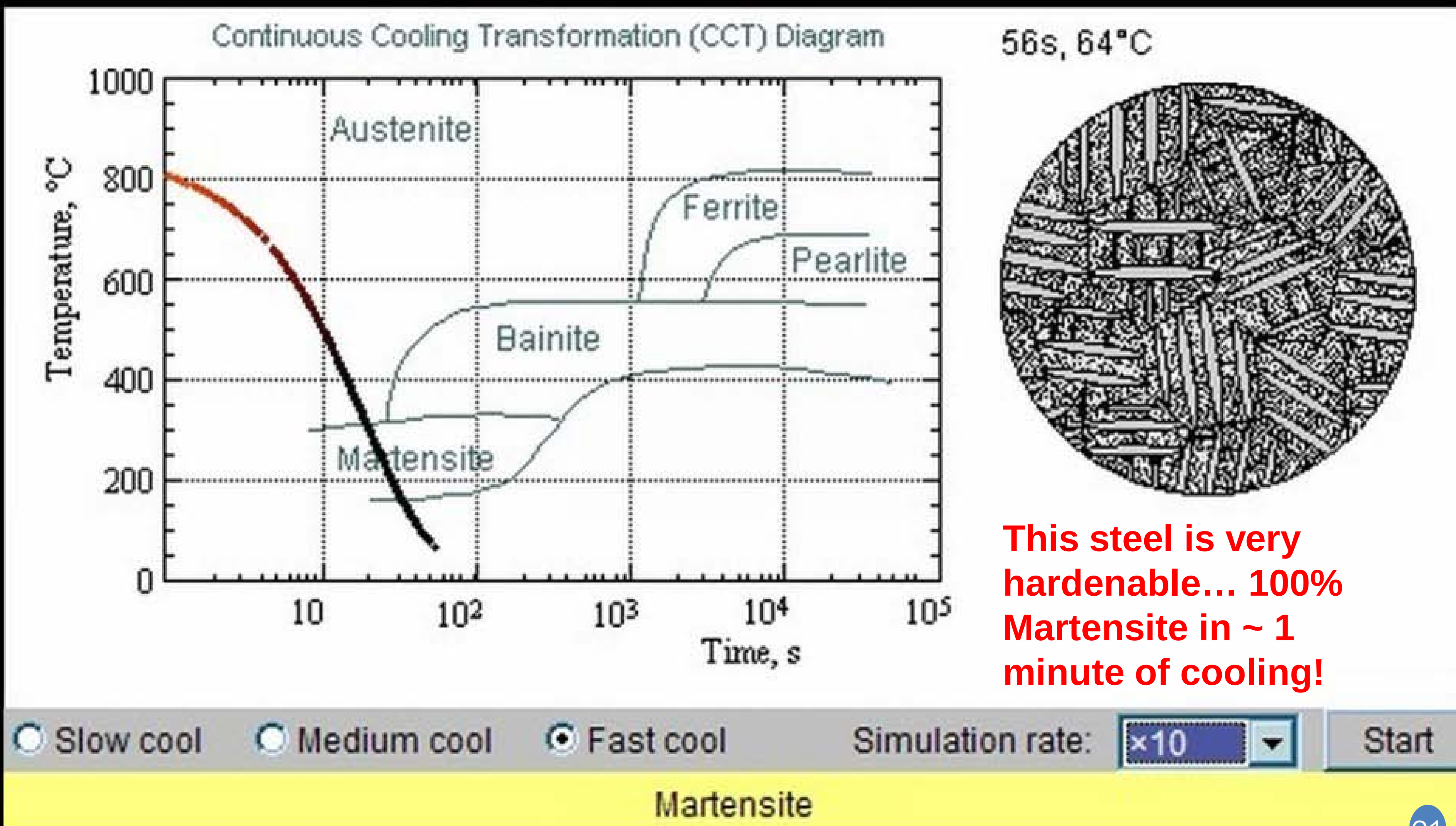


Medium Cooling



Cooling Rate, R, is Change in Temp / Time °C/s

Fast Cooling

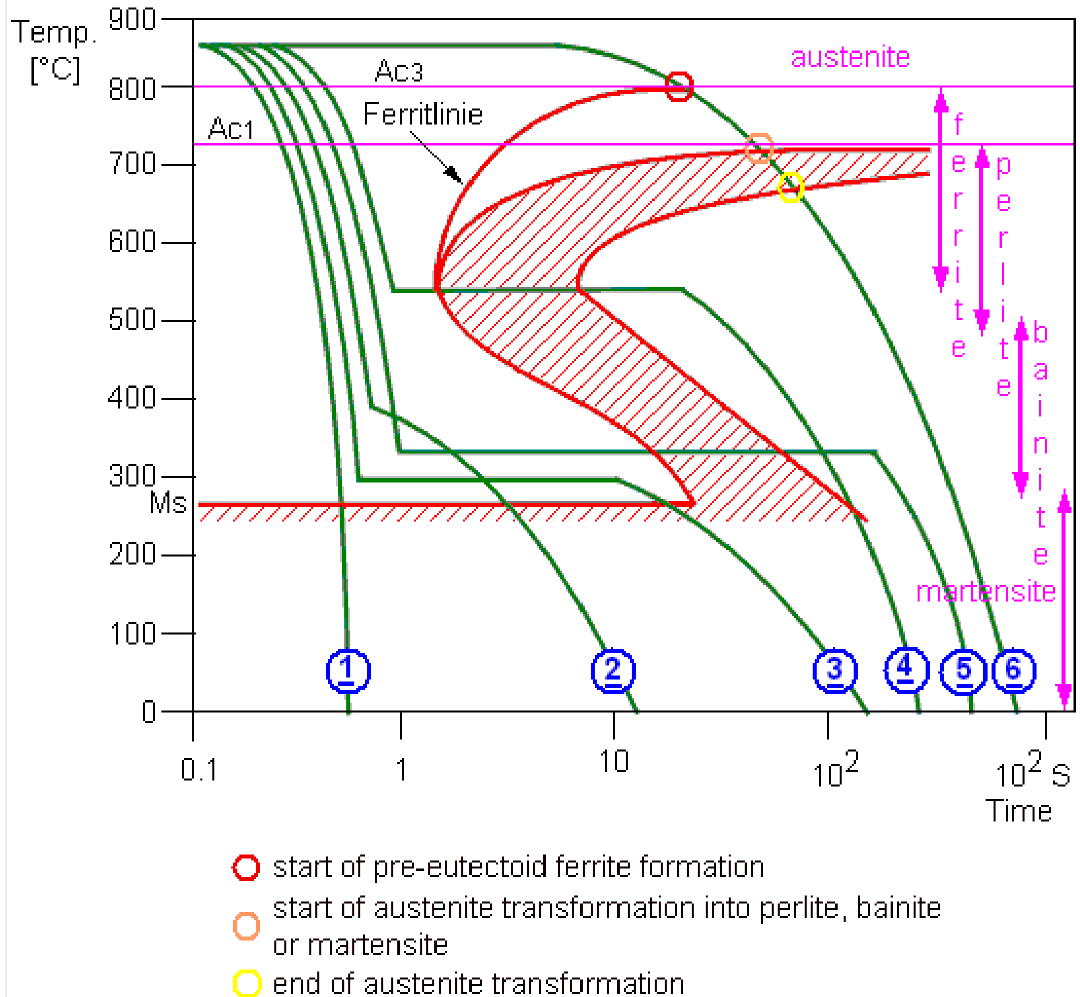


This steel is very hardenable… 100% Martensite in ~ 1 minute of cooling!

Schematic TTT Diagram With Different Heat Treatment Processes

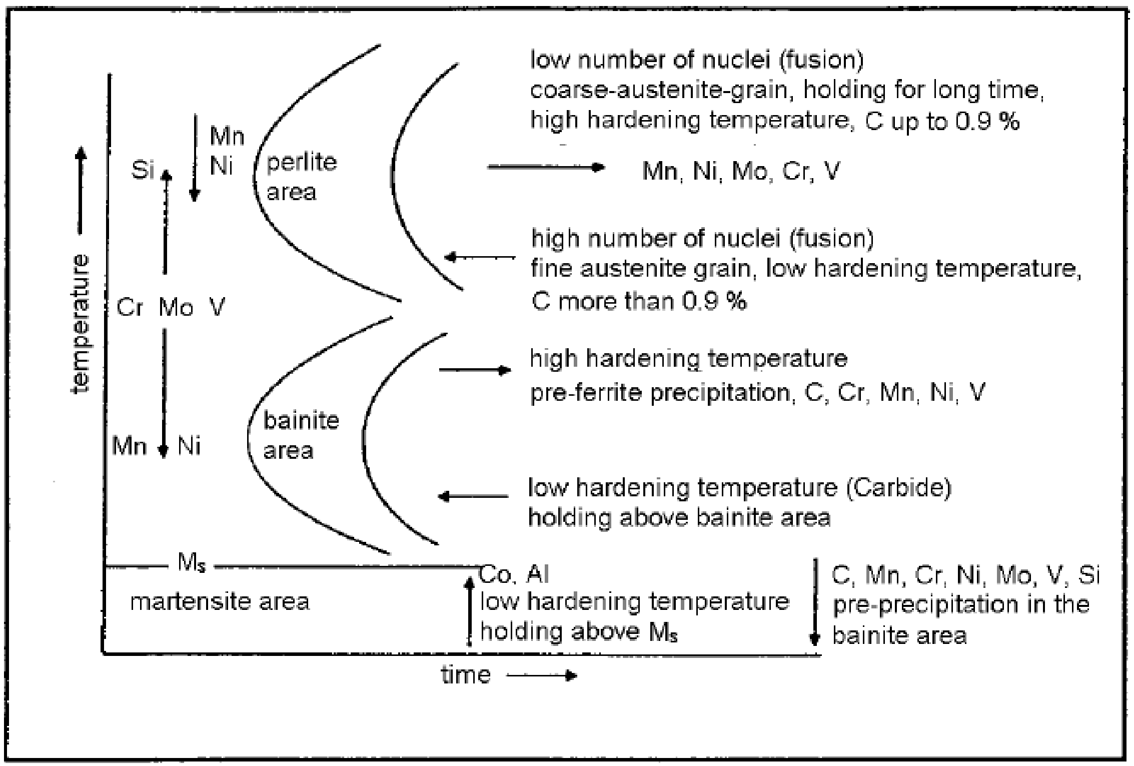
- The thermal treatment used for steels can be transferred schematically to a TTT diagram.

Curve 1: Hardening
Curve 2: "Broken" hardening
Curve 3: Martempering
Curve 4: Patenting
Curve 5: Austempering
Curve 6: Normalizing

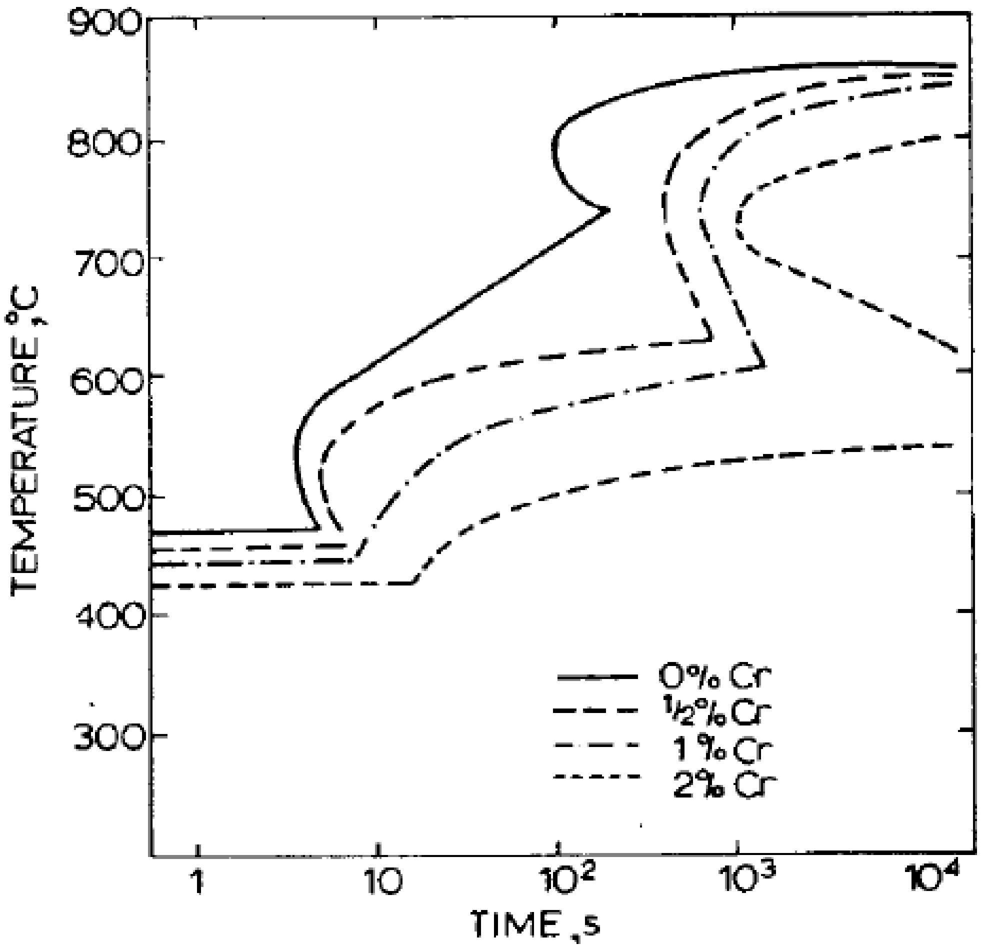


Influences of Alloying Elements on the Austenite Transformation

- The transformation ranges during the austenite transformation are influenced by the alloying elements both, in their temperature and in their chronological situation. Therefore, the alloying elements e.g. Cr, V and Mo lead to an increase of the pearlite stage as well as to a decrease of the bainite stage. At the same time, both of these transformation stages are displaced to longer periods



Influence of Cr on the Isothermal Transformation of a Steel with 0.15 % C, 0.5 % Mo, X%Cr.



Welding TTT Diagram

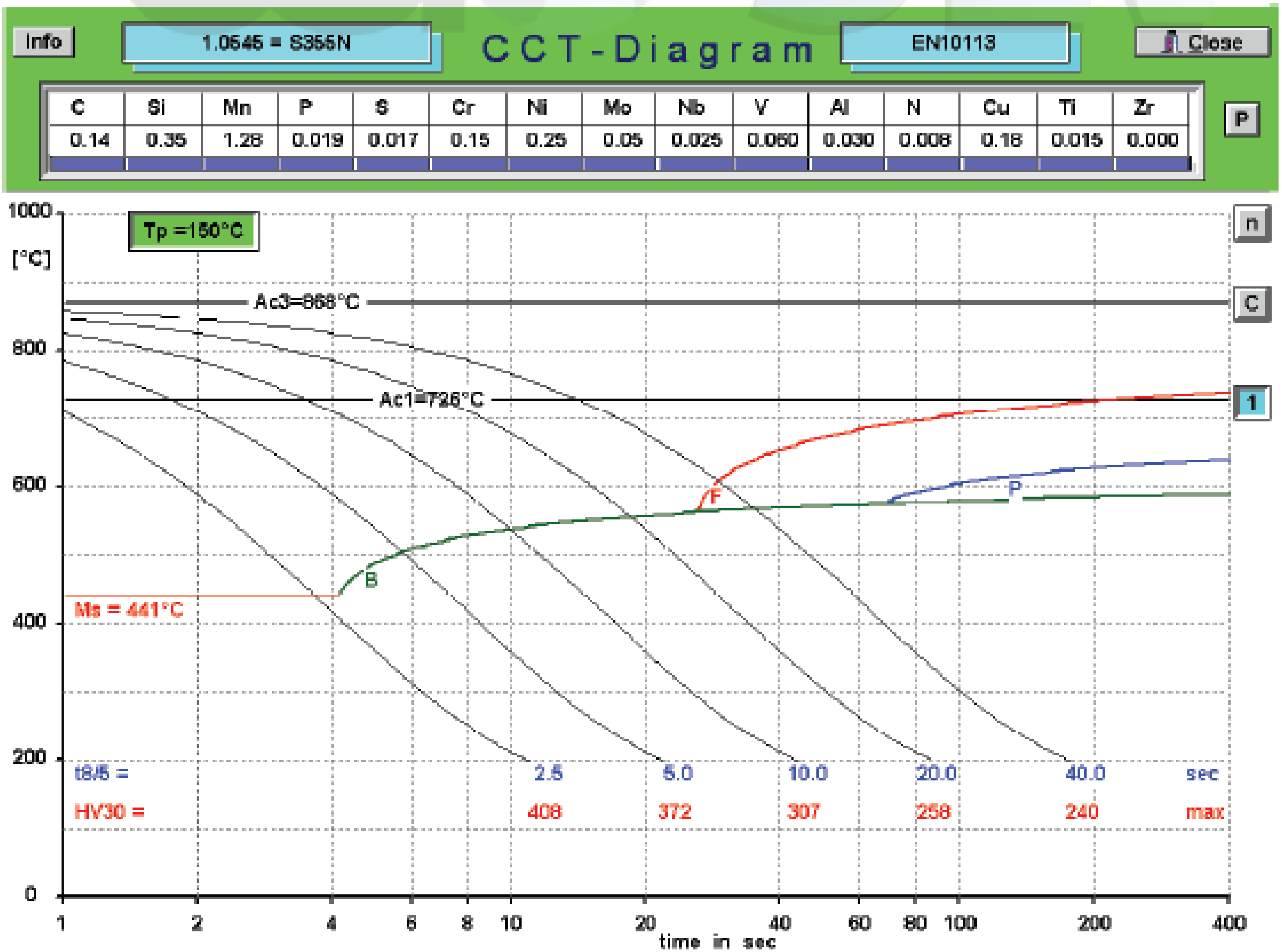
- Welding TTT diagram enable to foresee the weldability of a material, especially to point out the lower and upper critical cooling speed.
- The differences of a welding TTT diagram and a conventional TTT diagram are:

  - a higher austenitizing temperature for welding TTT diagram

  - a higher cooling speed than conventional TTT diagram

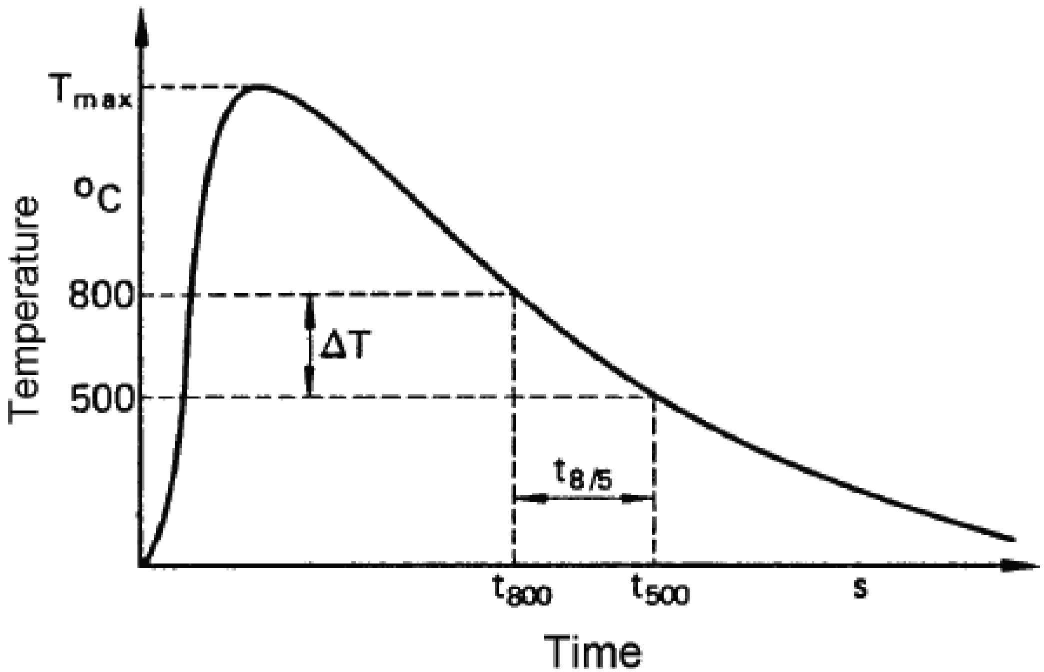
  - validity only for HAZ, not weld deposit.

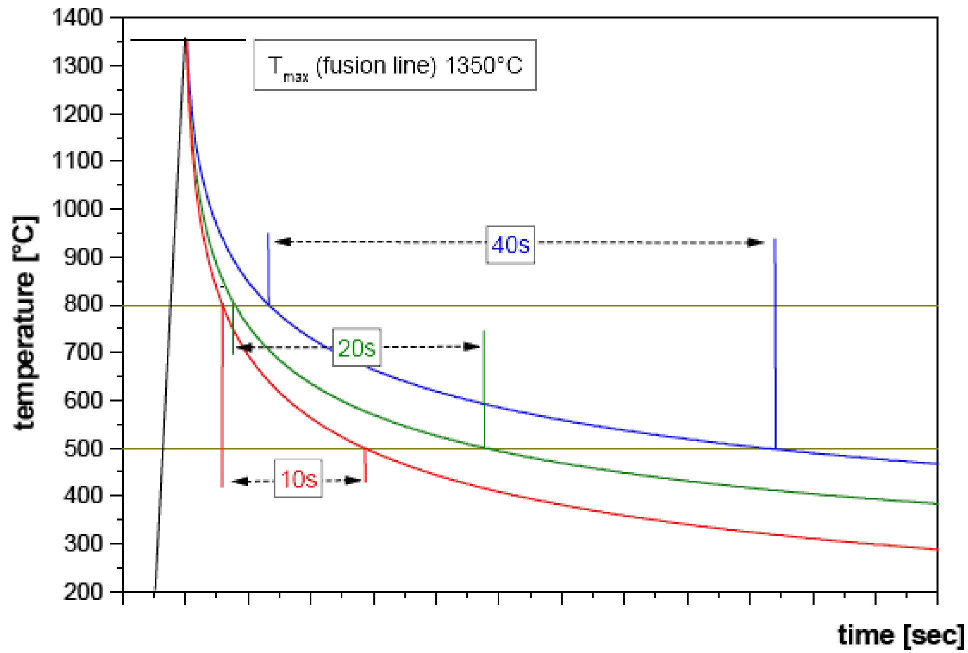
A Real Welding Diagram



Cooling Time ($t_{8/5}$ Concept)

- A significant value in welding is the $t_{8/5}$-value, which indicates the interval in which the temperature of the bead and its HAZ drops from 800 to 500°C.





Cooling $t_{8/5}$-time is depending on:

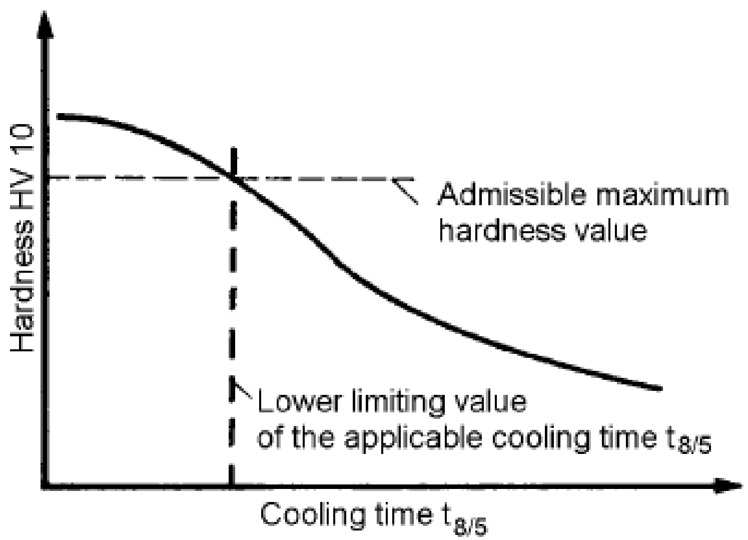
- heat input, Q, preheat- or interpass temperature T,joint geometry f,plate thickness d (for 2-dimensional heat flow)

For d> 20-30 mm plate thickness and T=200°C
cooling time [sec] is appr. 10-time the heat input [kJ/mm]
70 mm, 200 °C, 2.5 kJ/mm : t 8/5 appr. 25 sec

Cooling Time as a Function of Heat Input

Importance

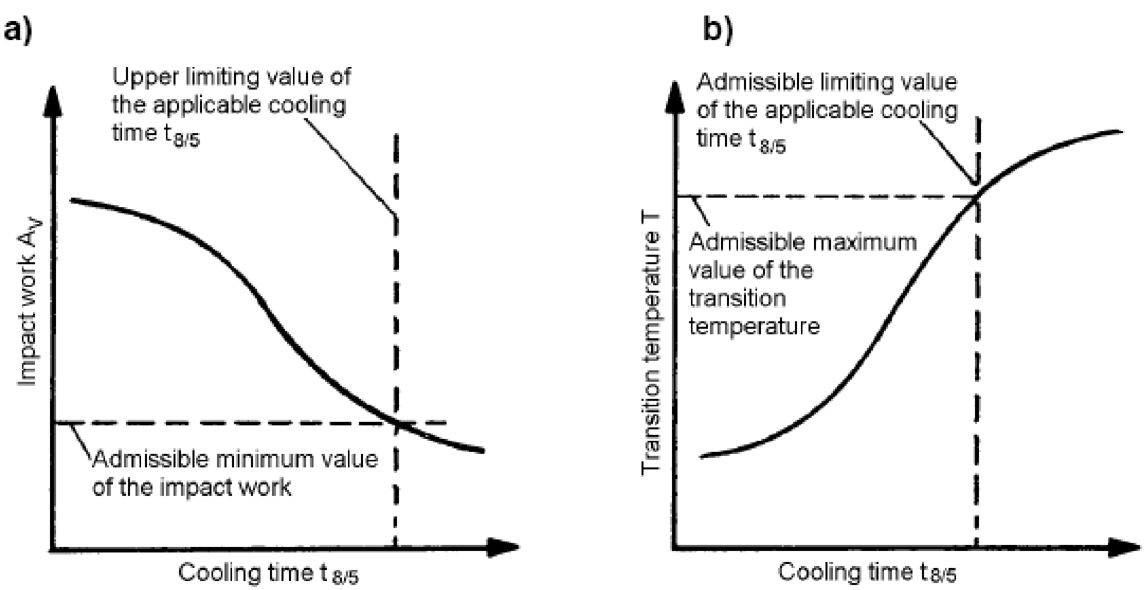
- The maximum values of hardness in the heat affected zone decrease with a raising cooling time $t_{8/5}$.If a defined maximum value of hardness in the heat affected zone must not be exceeded, the welding conditions must be chosen such that the cooling time $t_{8/5}$ will not fall below a defined value.



Influence of the welding conditions on the maximum hardness value in the heat affected zone

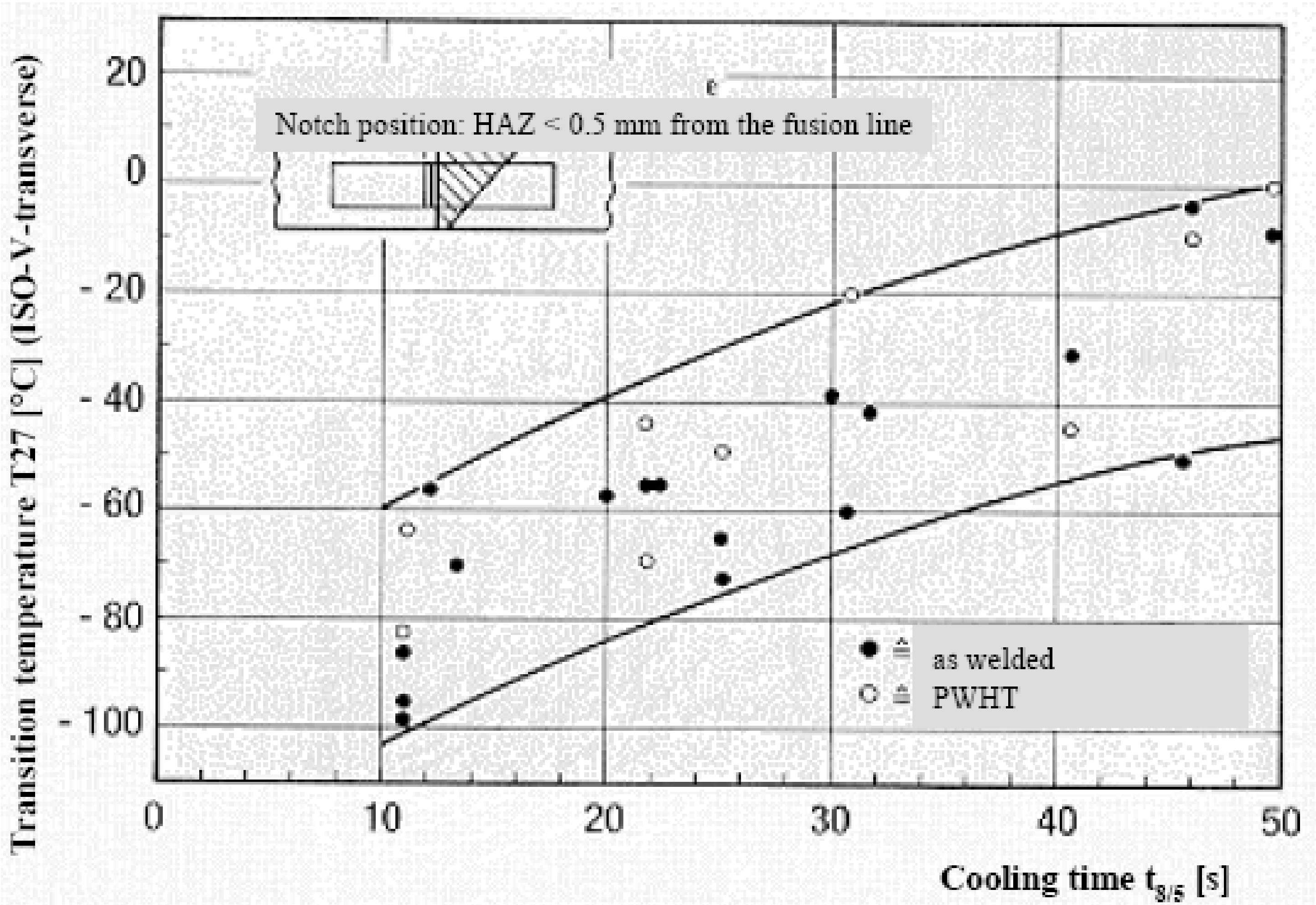
Importance (Cont'd)

- On the other hand, raising values of the cooling time $t_{8/5}$ lead to a decrease of the impact work of the heat affected zone. If the defined value of the impact work for a certain steel must not fall below a given minimum value, the welding conditions must be chosen in such a way that a defined value of the cooling time $t_{8/5}$ is not exceeded.



Influence of the welding conditions a) on the impact work and b) on the transition temperature of the impact work in the heat affected zone

HAZ Toughness



Determination of the Cooling Time $t_{8/5}$

- The following is for a three-dimensional dissipation of the welding heat, i.e. during welding at thick metal plates:

$$t_{8/5} = (6700 - 5 \cdot T_0) \cdot Q \cdot \left(\frac{1}{500 - T_0} - \frac{1}{800 - T_0} \right) \cdot F_3$$

- For the two-dimensional heat dissipation at thinner plates the following is valid:

$$t_{8/5} = (4300 - 4{,}3\, T_0) \cdot 10^5 \cdot \frac{Q^2}{d^2} \cdot \left[\left(\frac{1}{500 - T_0} \right)^2 - \left(\frac{1}{800 - T_0} \right)^2 \right] \cdot F_2$$

The higher value is valid !

Short character	Unit	Concept
$t_{8/5}$	s	Cooling time
Q	kJ/mm	Heat input ($Q = k \cdot E$)
k	--	Thermal efficiency (table 2)
E	kJ/mm	Energy per unit length ($E = U \cdot I \cdot 10^{-3}/v$
U	V	Arc voltage
I	A	Welding current
v	mm/s	Welding speed
T_0	°C	Pre-heating temperature
d	mm	Plate thickness, Component thickness
d_u	mm	Transition thickness
F_3, F_2	--	Seam factor with three- or two-dimensional heat dissipation (table 3)

Table 2: Relative efficiency of welding processes

Welding process	Relative thermal efficiency k
Submerged arc welding	1
Hand arc welding, alkaline cladded rod electrode	0,8
Metal active gas welding	0,85
Metal inert gas welding	0,75

Table 3: Influence of the type of seam on the cooling time $t_{8/5}$.

Type of seam	Seam factor F_2 two-dimensional heat dissipation	Seam factor F_3 three-dimensional heat dissipation
Surfacing bead	1	1
Filler pass of a butt joint	0,9	0,9
Single layer fillet weld at the corner joint	0,9 ... 0,67	0,67
Single layer fillet weld at the T-joint	0,45 ... 0,67	0,67

Recommendations for Welding

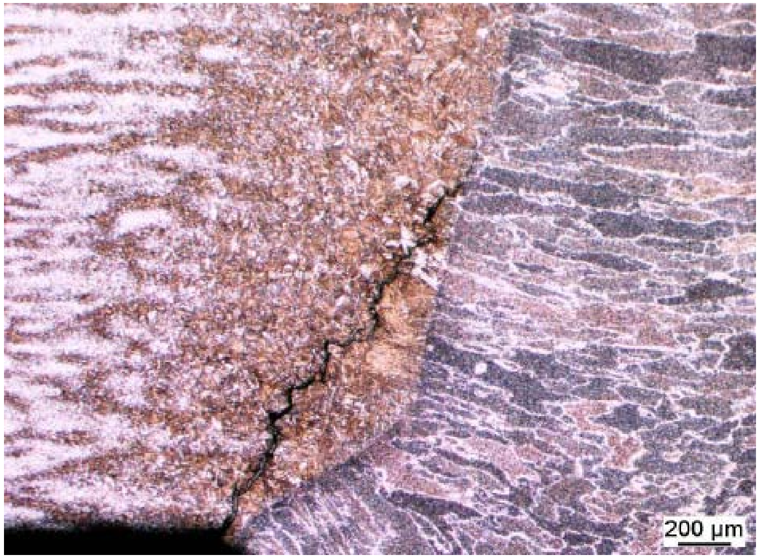
- To avoid cold cracking:

  minimum preheating temperature and

  minimum heat input

- To avoid softening:

  maximum cooling time $t_{8/5}$ -not to exceed



Useful web addresses

Get TTT and CCT Diagram with Steel Composition

Instructions: Type in the Steel Compositions and CCT details and and press 'Make Graph'.
(Make sure that concentration of alloying elements are less than 5 wt.%)

Carbon wt.%:	0.1	Silicon wt.%:	0.2	Manganese wt.%:	1.00
Nickel wt.%:	0.5	Molybdenum wt.%:	0.5	Chromium wt.%:	0.5

http://calculations.ewi.org/vjp/secure/TTTCCTPlots.asp

Austenitizing Temperature / Kelvin (you can input 0, if you

Minimum Cooling Rate K/s: 0.01

Maximum Cooling Rate K/s: 100

Minimum Time in Graph: 0.01

Maximum Time in Graph: 1000

Welcome to Kaker.Com

CCT and TTT Diagrams of Steels - The database contains 4900 transformation diagrams (CCT and TTT diagrams) of steels collected from the journals, books, company prospects and web sites from the year 1939 (Davenport) to the year 2011.

Etchants Database - The database of 11,300 etchants and electropolishing procedures collected from the books and journals.

Hardenability Diagrams of Steels - The database contains 1365 hardenability diagrams of steels collected from the year 1951 to the year 2010.

Steel Data Service - Technical steel data service.

http://kaker.com/

Tempering Diagrams of Steels - The database contains 1608 tempering diagrams of steels collected to the year 2011.

Microscopy Vendors - Free microscopy vendors database is one of the largest microscopy vendors database in the world.

Free Software - Collection of our free software: EPMA Database, Microanalysis Programs for PC, Connection Edax 9100-PC, Spectrum Plotting and Printing Programs and Microanalysis subprograms written in the Basic.

Let’s Have a Look at SLV Software(Part 2.5)

Prepared By: Kamran Khodaparasti
kkhodaparasti@yahoo.com

First Edition: Fall 2009
First Revision: Winter 2009
Second Revision: Winter 2010
Third Revision: Summer 2012