Steels & Stainless Steels I

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Mechanical & Materials Engineering for
Particle Accelerators and Detectors

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Sint-Michielsgestel, NL

Outline

1. Introduction to steels and stainless steels
    - Iron and steel, major players in the history of mankind
    - Stainless steels, a 100 years of know-how
2. Metallurgy
    - phases, properties, microstructures
    - the Fe-C (Fe-Fe_3C) diagram
    - families of steels
    - steels and irons
3. Steelmaking practice
    - Heat treatments and practice
    - Tailoring the properties of heat treatable steels
4. Case studies
5. Conclusions

1. Introduction

Remains of Etruscan furnaces, exploited from the end of the Iron Age (9th – 8th century BC) to the 1st century BC

A. Berveglieri, R. Valentini, La Metallurgia Italiana, June 2001, p. 49ff

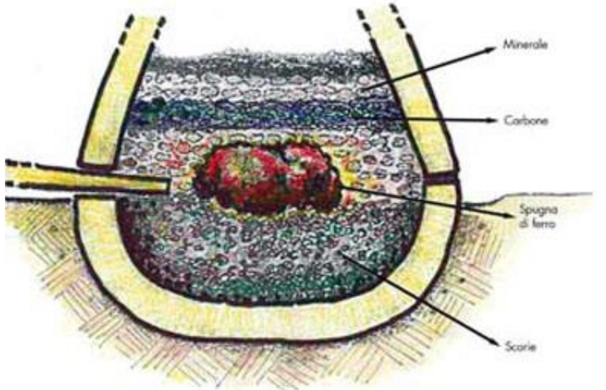
Fig. 2 – La posizione geografica di Populonia.
Fig. 2 – Geographical location of Populonia.

Residues, exploited until 1969...

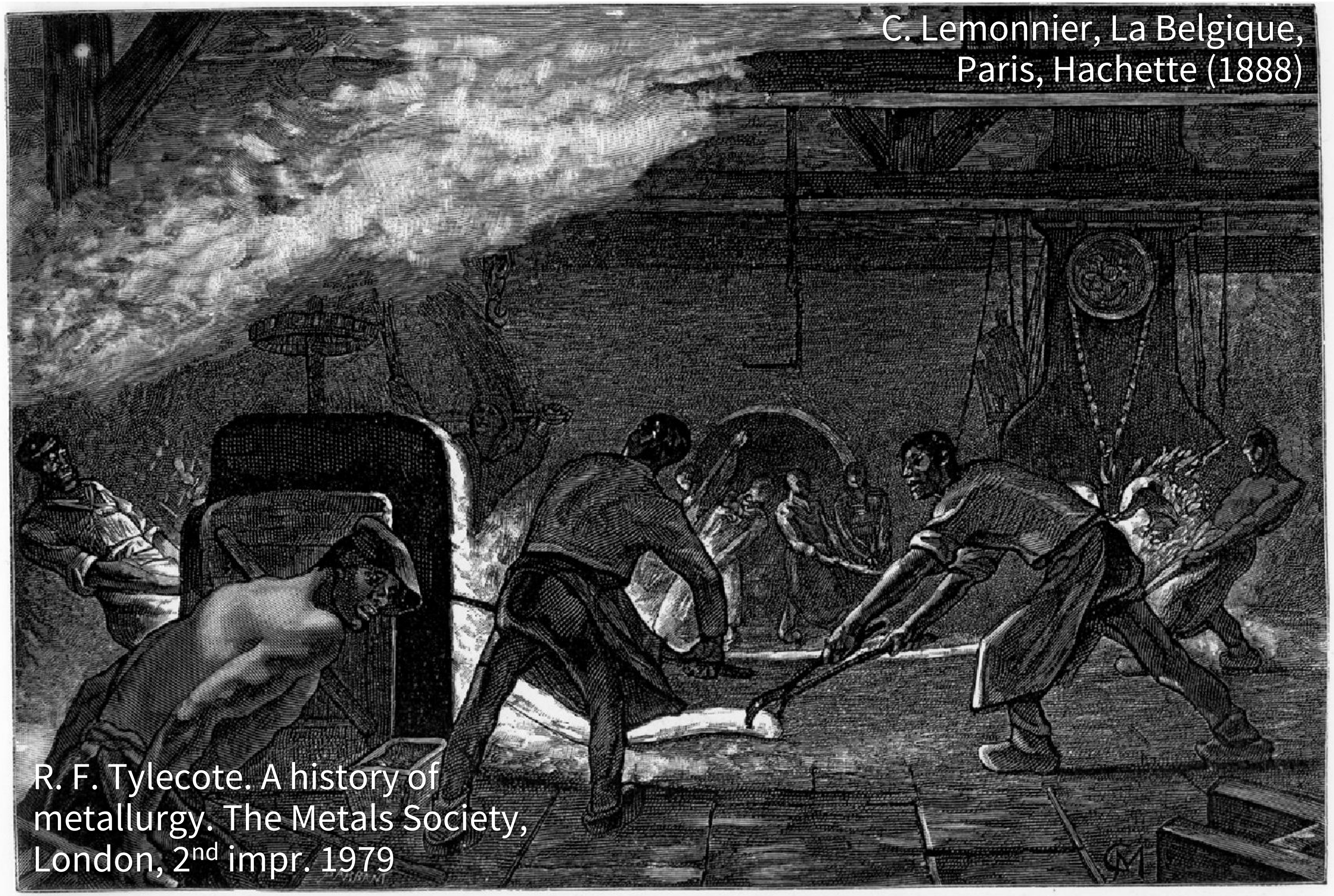
$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$

$FeO + CO \rightarrow Fe + CO_2$

$FeO + C \rightarrow Fe + CO$



1. Introduction



C. Lemonnier, La Belgique,
Paris, Hachette (1888)

R. F. Tylecote. A history of metallurgy. The Metals Society, London, 2nd impr. 1979

Dessin de Constantin Meunier.

TRAIN DE LAMINEURS DANS UN LAMINOIR DE MONTIGNY-SUR-SAMBRE.

1. Introduction

Courtesy of TISCO /CN, hot rolling stainless steel plate mills, 2018

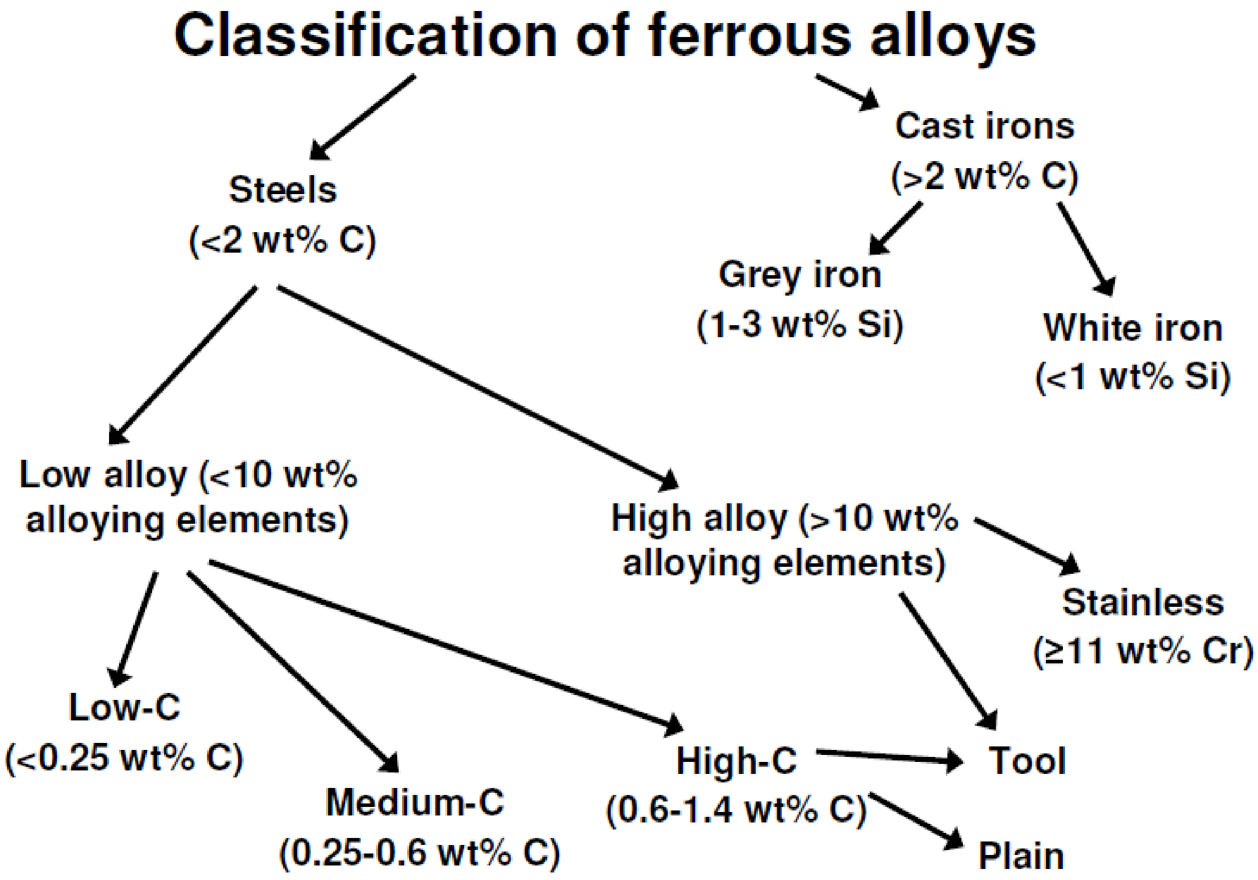
1. Introduction

The Sandviken site in Sweden

- **SMT main site** with steel mill and manufacturing of bar, tube, strip and wire (~3500 employees)
- **Service HQ** located in the middle
- **R&D block** with labs and experts (~250 employees)
- **Additional manufacturing and R&D units** in US, Canada, Norway, Germany, France, Czech republic, India and China

Courtesy of Sandvik Stainless Services

1. Introduction



Classification of ferrous alloys

Steels
(<2 wt% C)

Cast irons
(>2 wt% C)

Grey iron
(1-3 wt% Si)

White iron
(<1 wt% Si)

Low alloy (<10 wt%
alloying elements)

High alloy (>10 wt%
alloying elements)

Stainless
(≥11 wt% Cr)

Low-C
(<0.25 wt% C)

Medium-C
(0.25-0.6 wt% C)

High-C
(0.6-1.4 wt% C)

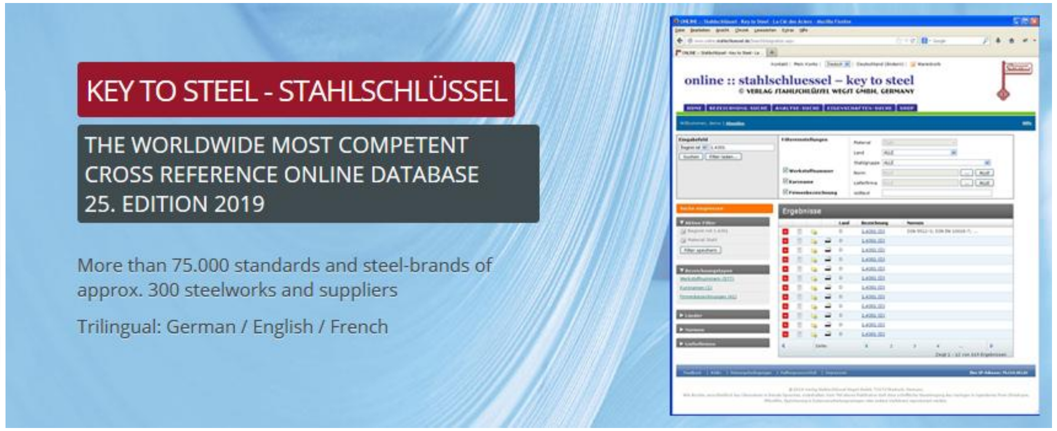
Tool

Plain

Steel is an iron based alloy containing Carbon, Silicon, Manganese etc.,
http://steel.nic.in/Glossary-I.pdf

Steel is an alloy of iron and carbon. The amount of carbon dictates whether a steel is hard or it is tough. C content in steel usually falls a range between 0.3 ~ 1.5 % by volume,
http://www.ksky.ne.jp/~sumie99/ironandsteel.html

See also comprehensive databases such as:
www.totalmateria.com



KEY TO STEEL - STAHLSCHLÜSSEL

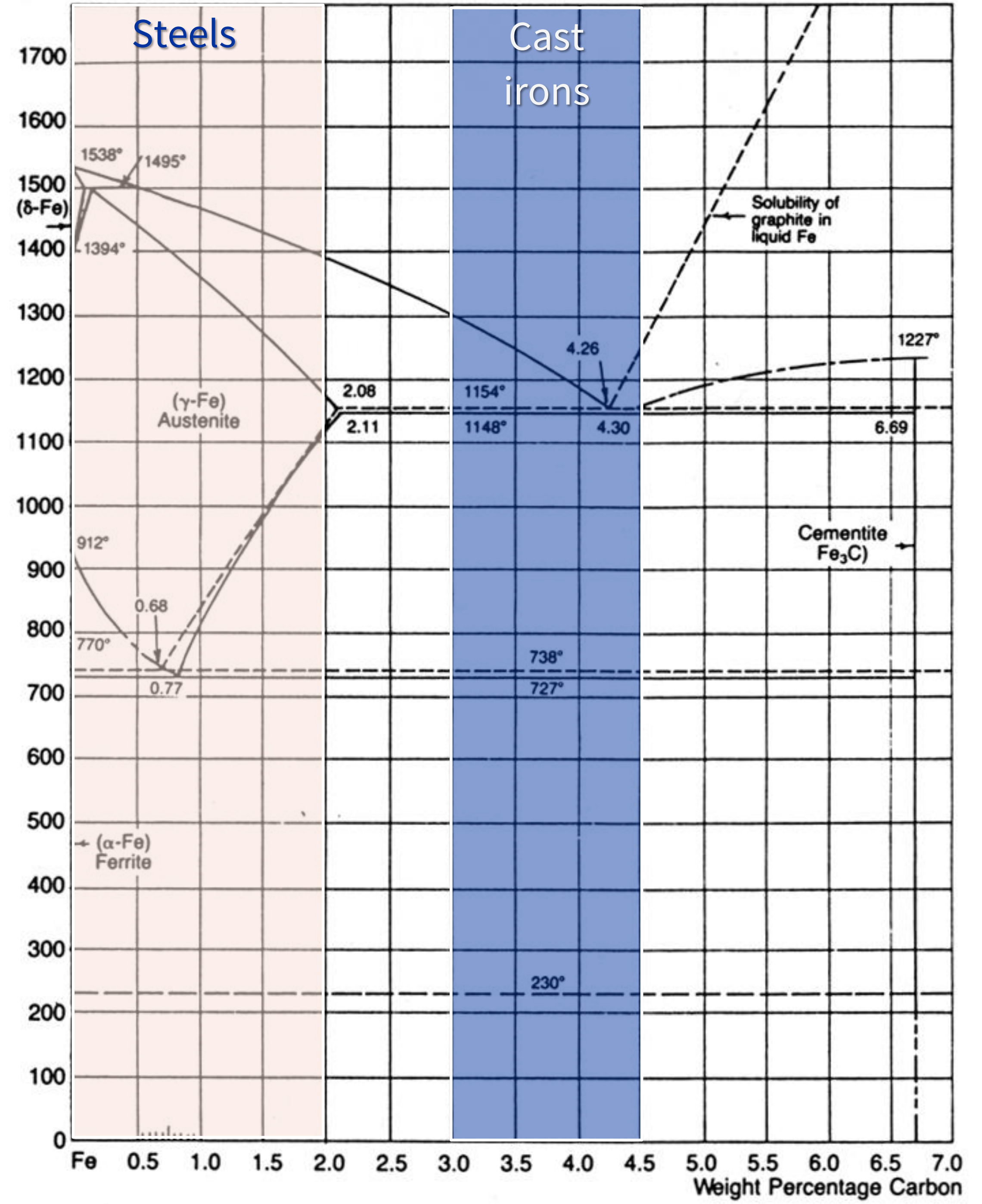
THE WORLDWIDE MOST COMPETENT
CROSS REFERENCE ONLINE DATABASE
25. EDITION 2019

More than 75.000 standards and steel-brands of approx. 300 steelworks and suppliers

Trilingual: German / English / French

1. Introduction

The Fe-C (Fe-Fe_3C) diagram



Fe_3C (metastable cementite) →
3 Fe + C (graphite)

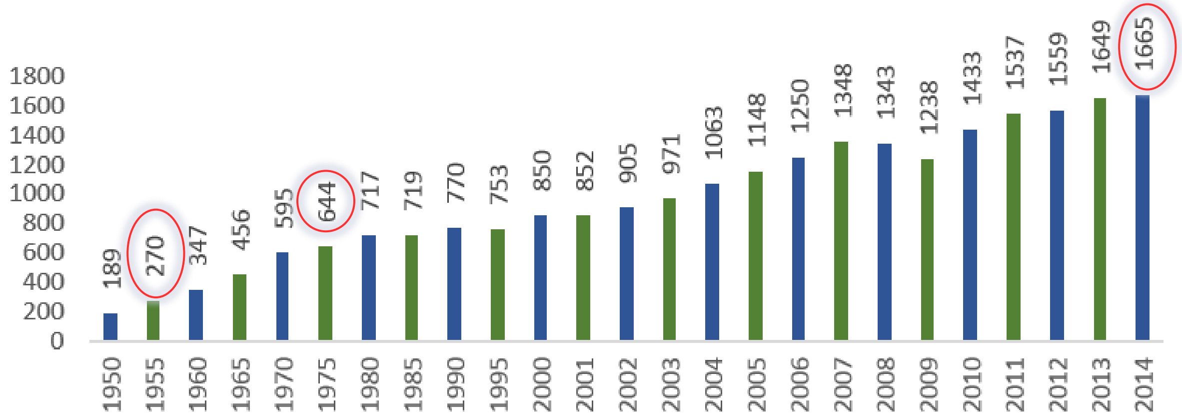
——— Fe - Fe3C

- - - - Fe - graphite

1. Introduction

Autostrada del Sole, first open section 1958

WORLD STEEL PRODUCTION, 1950-2014 (IN MILLION TONNES)



SOURCE: WORLD STEEL

A22, Autobrennero, 1974

Weathering steel COR-TEN trademark of United States Steel Corporation (USS): by amount of Cu, P Si and Cr, can develop under favourable climatic conditions a patina of hydrated Fe oxide retarding further attack. Long dry summer periods required.

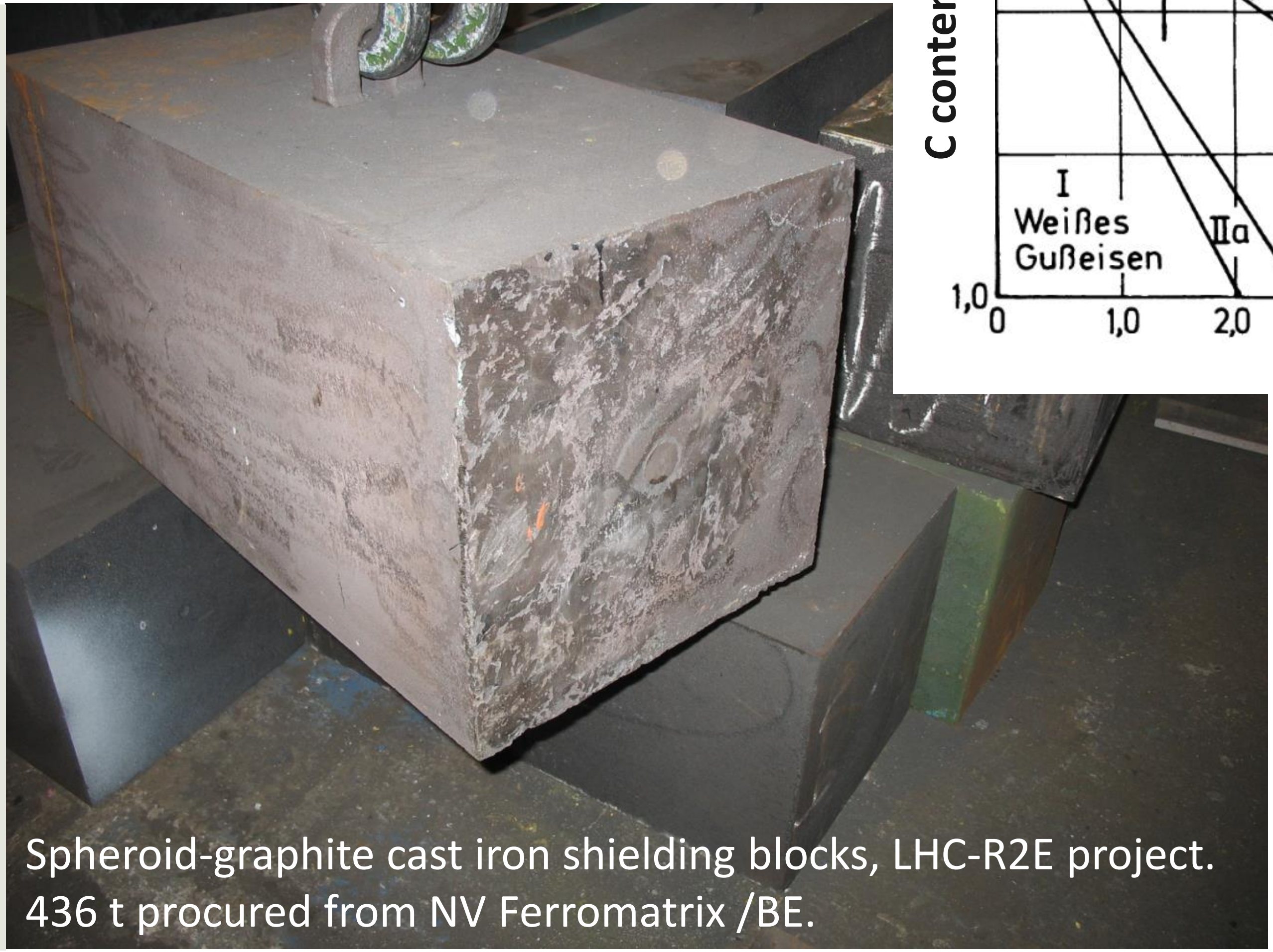
A2 (CH), Chiasso boundary, 2014

Hot galvanizing + powder coating

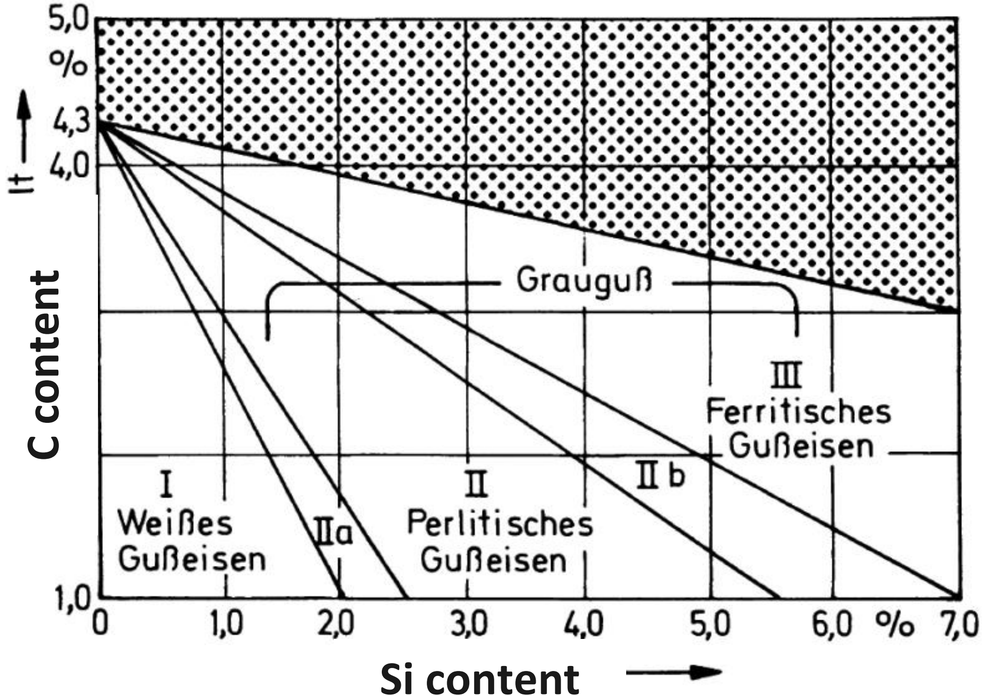
1. Introduction

Cast irons:

- Class of ferrous alloys with C ≥ 2.14 %
- Most contain 3.0 % ≤ C ≤ 4.5 %
- Lower T_m (1150 °C - 1300 °C) than steel
- Easily melted and amenable to casting
- Based on the reaction $Fe_3C \rightarrow 3\ Fe + C$
- Tendency to form graphite regulated by composition and rate of cooling



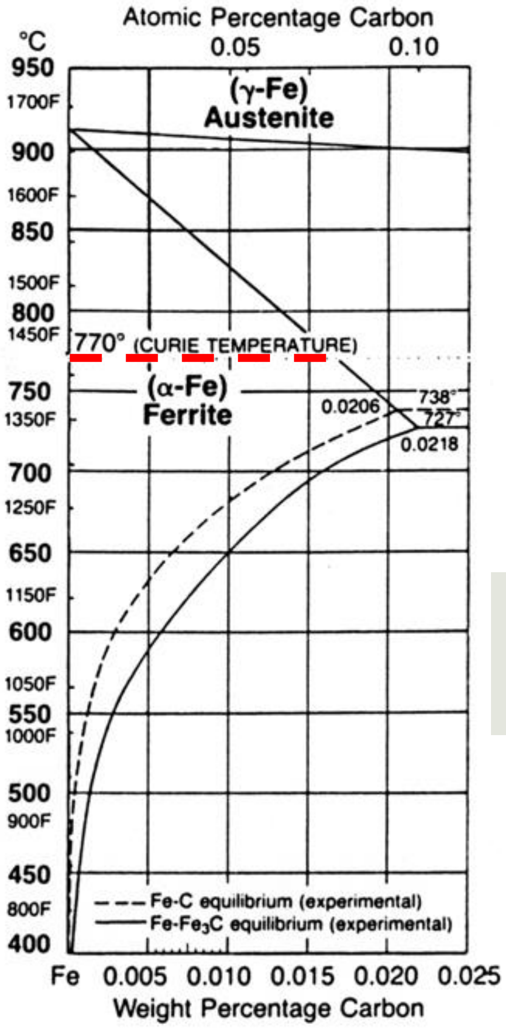
Spheroid-graphite cast iron shielding blocks, LHC-R2E project. 436 t procured from NV Ferromatrix /BE.

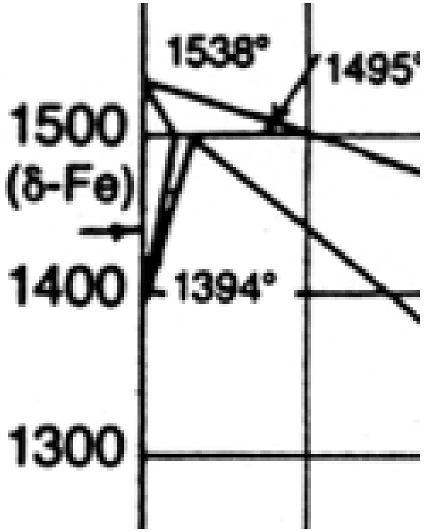


Maurer diagram (1924)

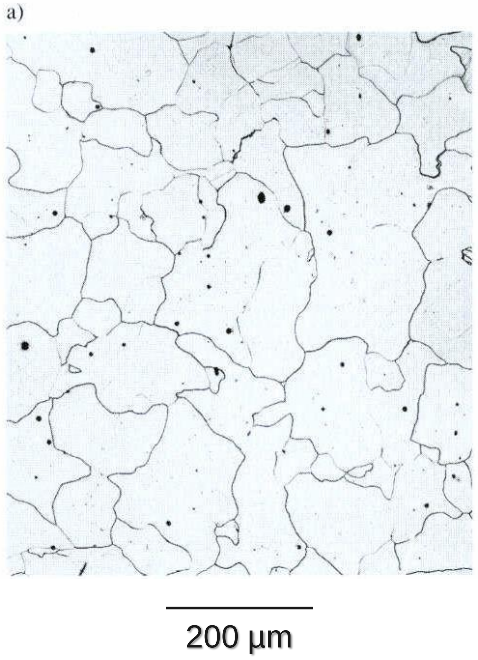
2. Metallurgy - Phases, properties, microstructures

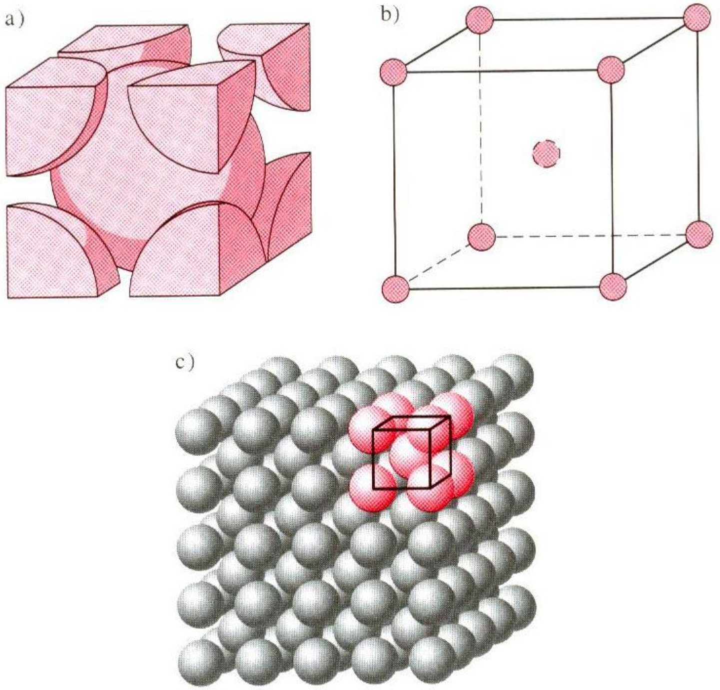
- bcc, non-compact (32 % empty space)
- available small but numerous interstitial sites
- faster diffusion
- smaller CTE
- ferromagnetic under T_c
- DBTT (ductile to brittle transition T)
- limited ductility, high strength
- high Young’s modulus
- yield strength well defined

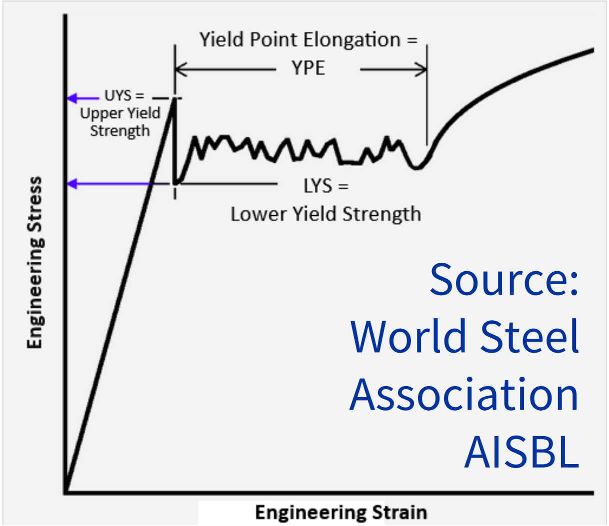




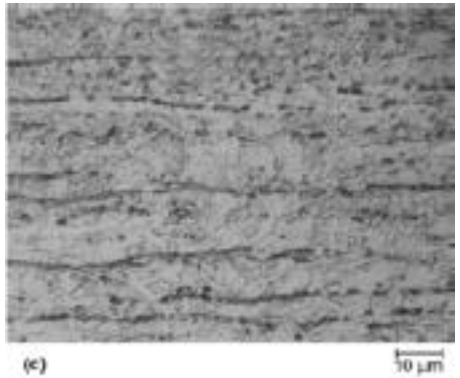
α(δ)-ferrite: a limited domain





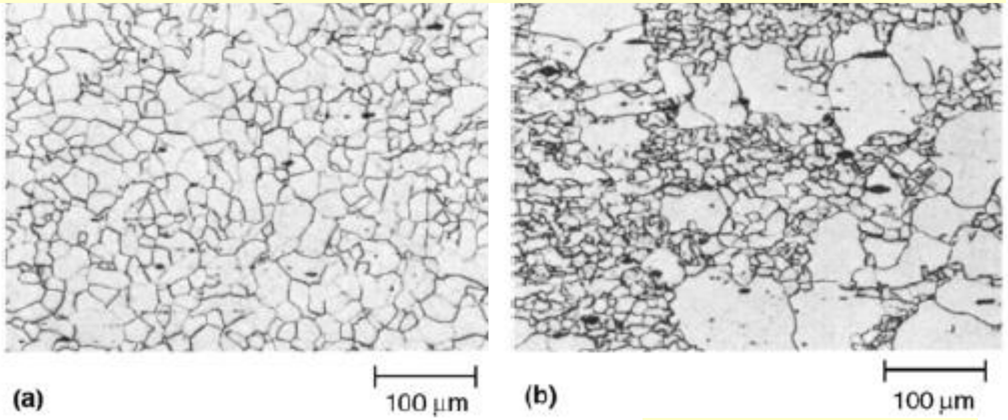


Source: World Steel Association AISBL

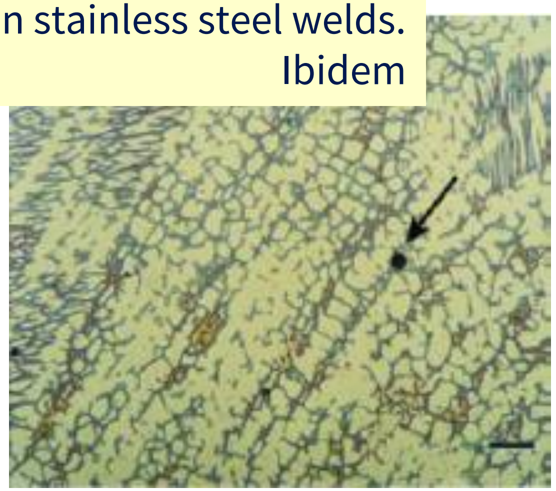


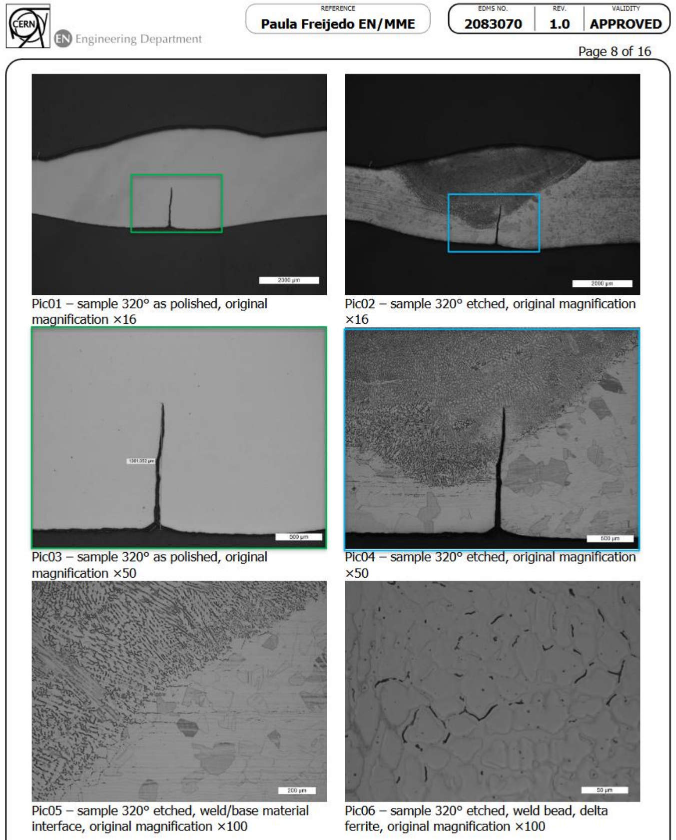
δ-ferrite stringers in 17-7 PH stainless steel after hot and cold processing. Source, ASM Handbook, Volume 9, *Metallography and Microstructure*

α-ferrite: 0.013% C steel, finish rolling at 940 °C (left) or 845 °C (right) and coiled at 725 °C. Ibidem



δ-ferrite in stainless steel welds. Ibidem




Engineering Department

REFERENCE	EDMS NO.	REV.	VALIDITY
Paula Freijedo EN/MME	2083070	1.0	APPROVED

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Pic01 – sample 320° as polished, original magnification ×16

Pic02 – sample 320° etched, original magnification ×16

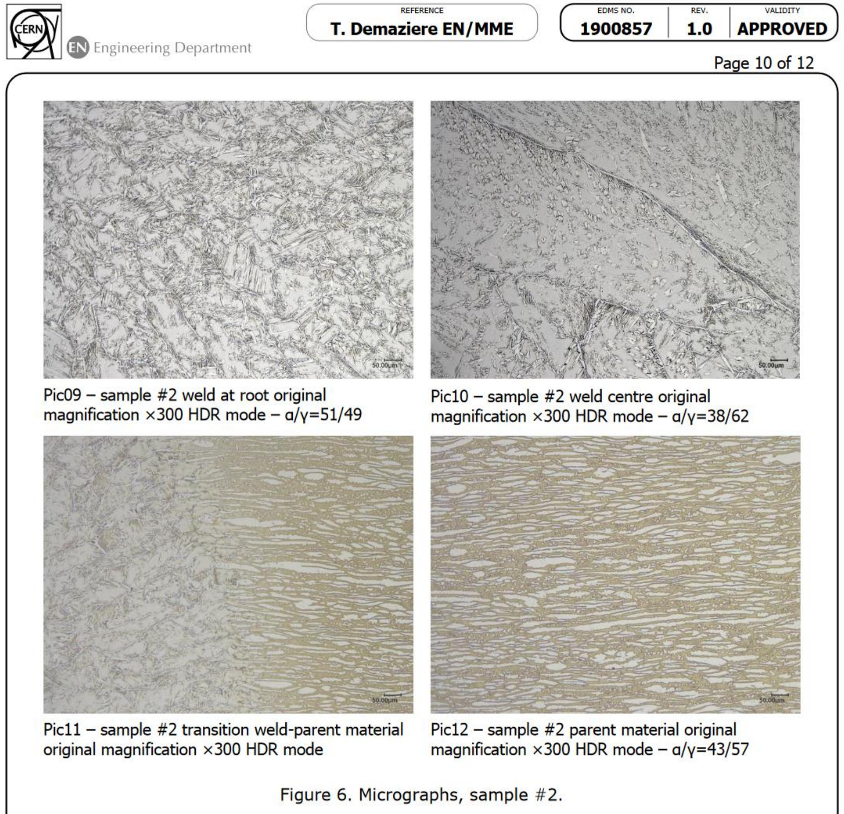
Pic03 – sample 320° as polished, original magnification ×50

Pic04 – sample 320° etched, original magnification ×50

Pic05 – sample 320° etched, weld/base material interface, original magnification ×100

Pic06 – sample 320° etched, weld bead, delta ferrite, original magnification ×100

δ-ferrite in a URANUS 45® duplex stainless steel and its welds (TDE beam dump at LHC Point 6), EDMS 1900857


Engineering Department

REFERENCE	EDMS NO.	REV.	VALIDITY
T. Demaziere EN/MME	1900857	1.0	APPROVED

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Pic09 – sample #2 weld at root original magnification ×300 HDR mode – α/γ=51/49

Pic10 – sample #2 weld centre original magnification ×300 HDR mode – α/γ=38/62

Pic11 – sample #2 transition weld-parent material original magnification ×300 HDR mode

Pic12 – sample #2 parent material original magnification ×300 HDR mode – α/γ=43/57

Figure 6. Micrographs, sample #2.

δ-ferrite under the form of stringers and as precipitated in a LS2 repair weld of a stainless steel LHC diode box (magnet 2303) – EDMS 2083070

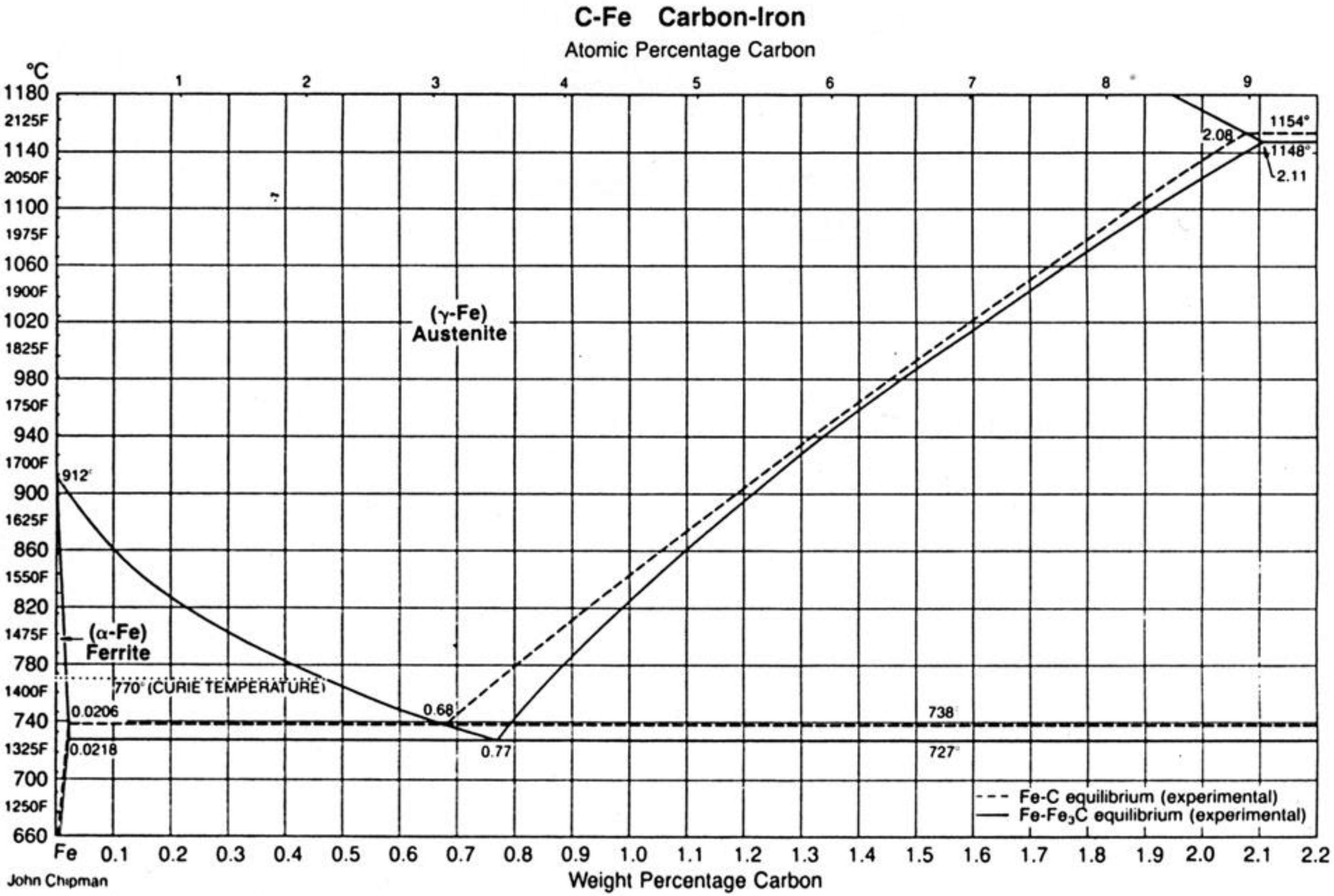
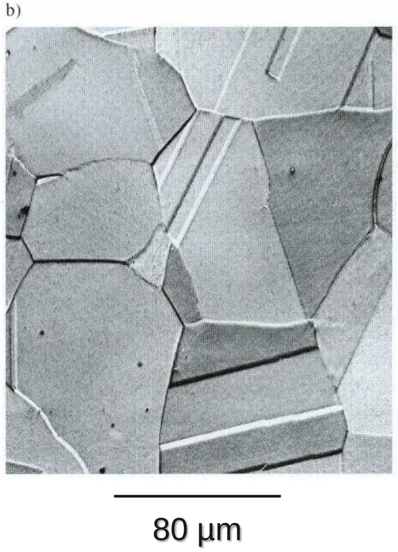


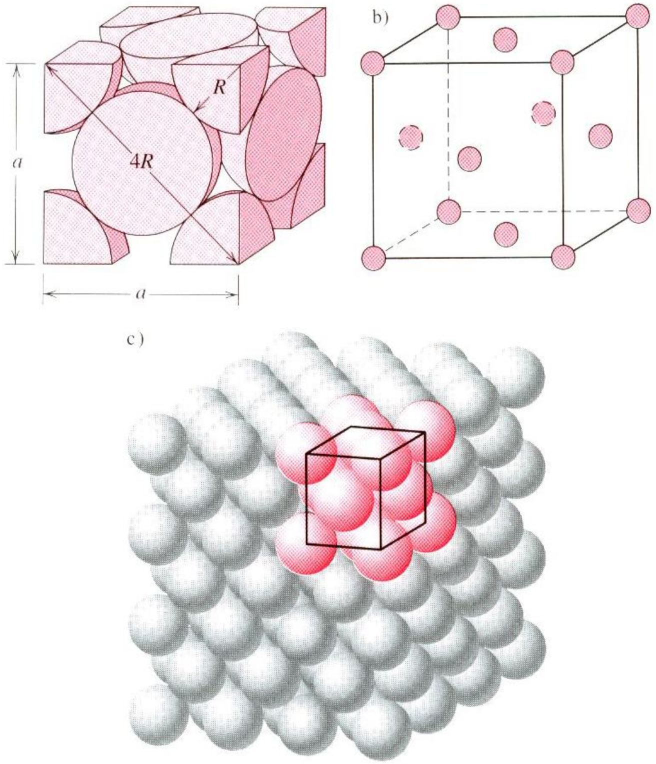
Fig. 2.1. Portion of the Fe-C diagram emphasizing regions of proeutectoid ferrite and cementite formation and the eutectoid transformation of austenite. (Ref 2.15)



γ-austenite: solid solution of C in γ-iron

Source: ASM Technical Books, Steels

2. Metallurgy - Phases, properties, microstructures



γ-austenite

- fcc, compact (24% empty space)
- available larger interstitial sites
- slower diffusion compared to bcc
- larger CTE
- paramagnetic
- absence of DBTT
- weaker Young’s modulus
- high ductility
- ill-defined yield strength

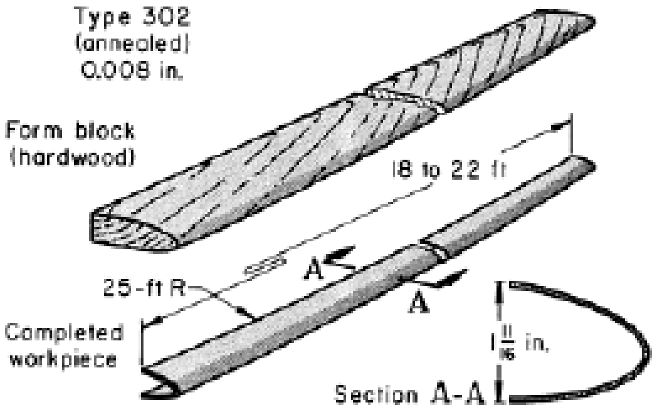
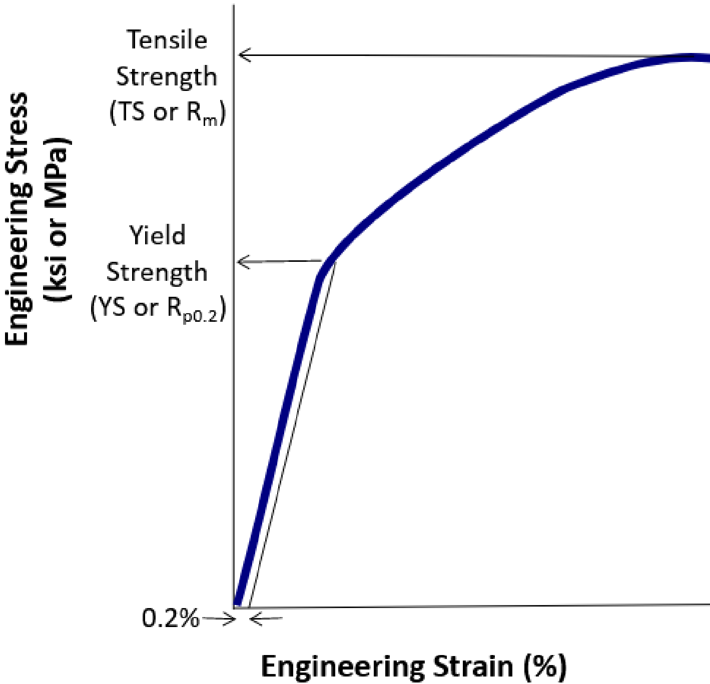


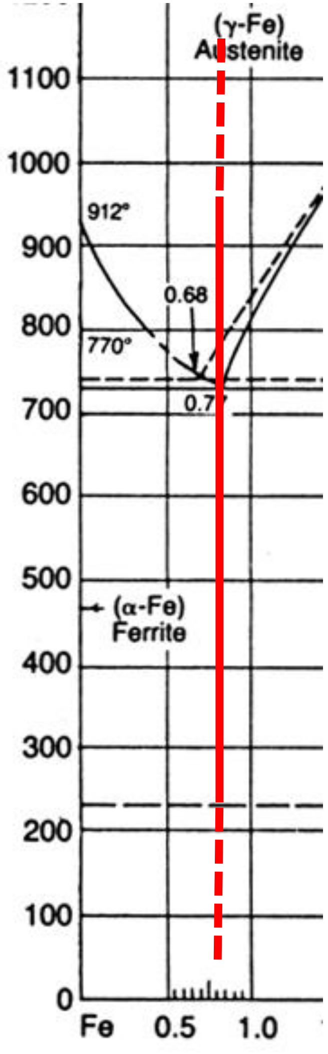
Fig. 30 Airfoil on which the leading edge was stretch formed to a long convex shape without lubricant in a radial-draw former.

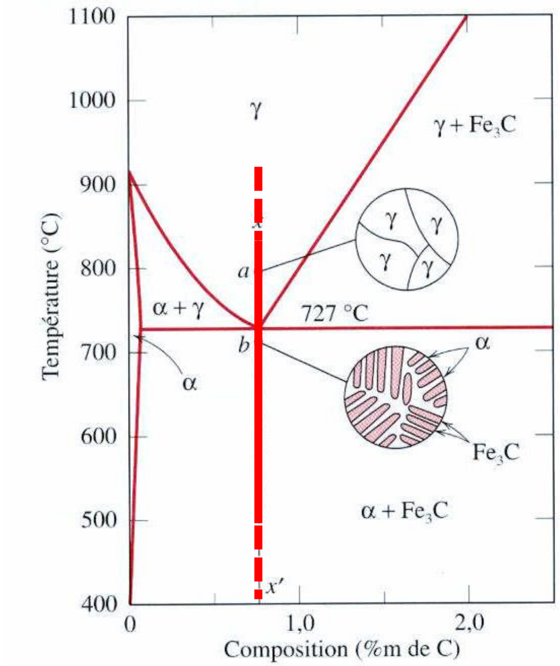
Source, ASM Handbook, Volume 14, Forming and Forging

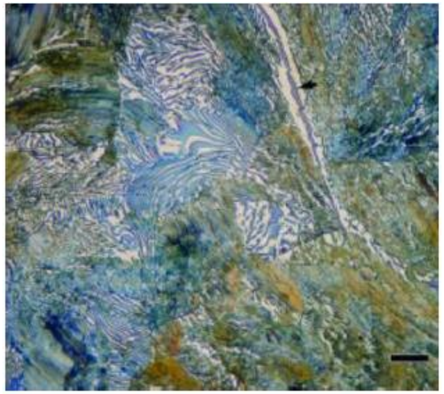


2. Metallurgy - Phases, properties, microstructures

The eutectoid transformation: pearlite

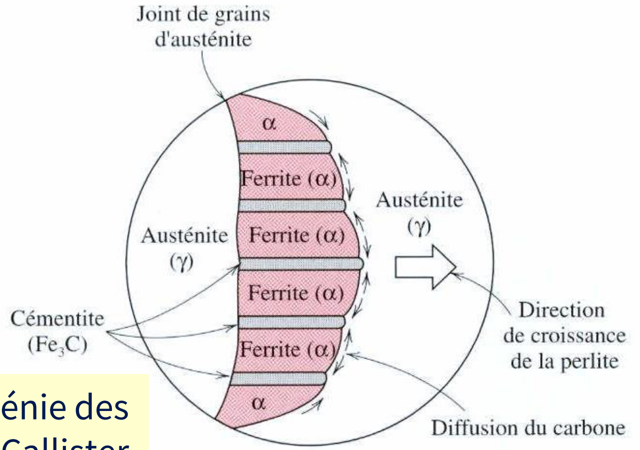






Cementite in an as-hot-rolled Fe-1%C binary alloy (arrow) The etch also colored the cementite in the pearlite.
Source, ASM Handbook, Volume 9, Metallography and Microstructure

"True" Damascene blade. The Damascene (or water) pattern comes from a striated precipitation of Fe$_3$C particles and not from folding and welding



Source: Science et génie des matériaux, W. Callister

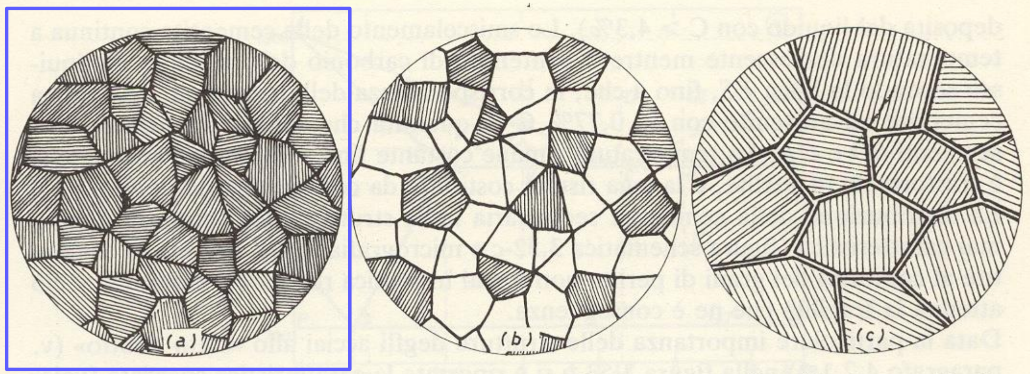
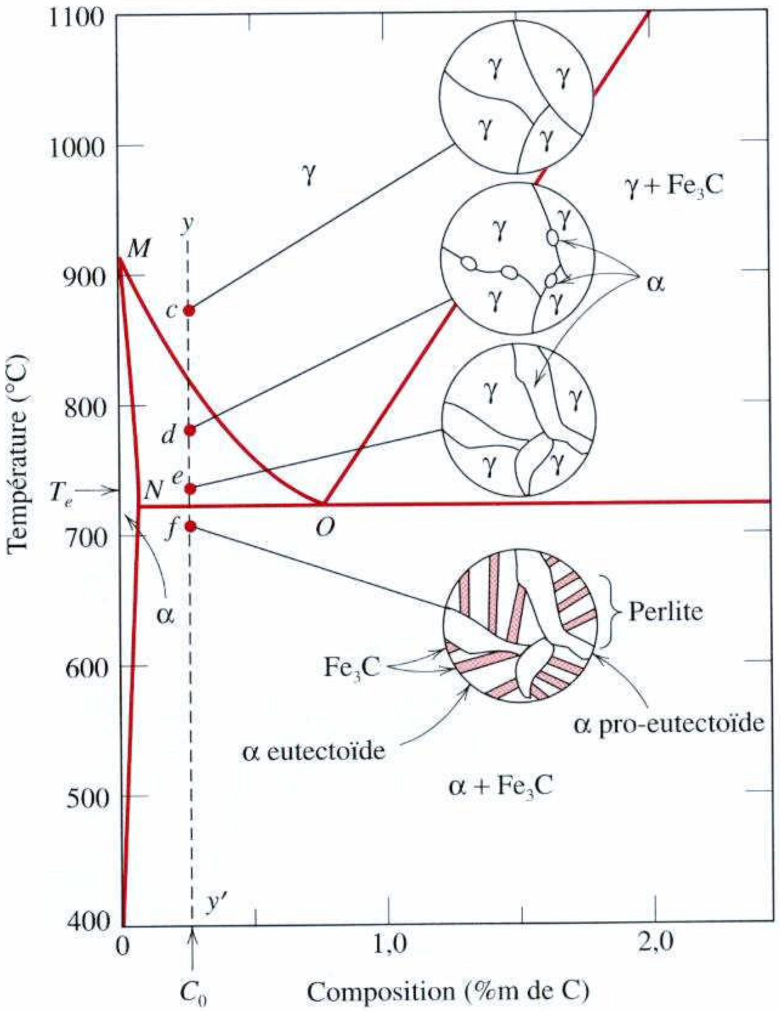
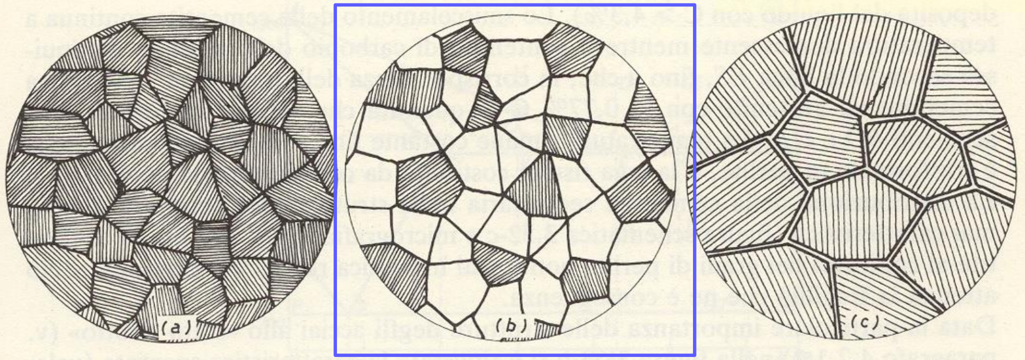


Fig. 3.52 *Rappresentazione schematica delle strutture allo stato ricotto di acciai: a) eutettoide; b) ipo-eutettoide; c) ipereutettoide.*

2. Metallurgy - Phases, properties, microstructures

Hypoeutectoid steels





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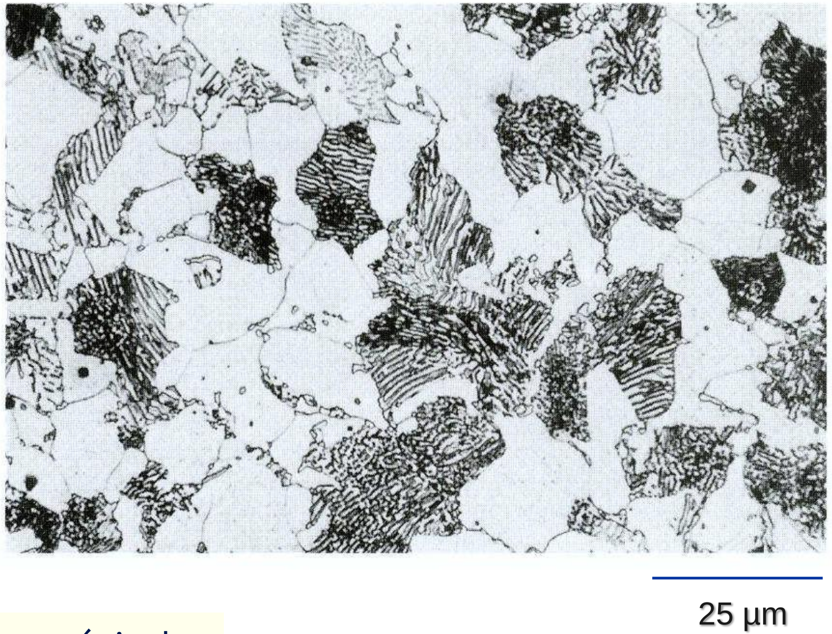
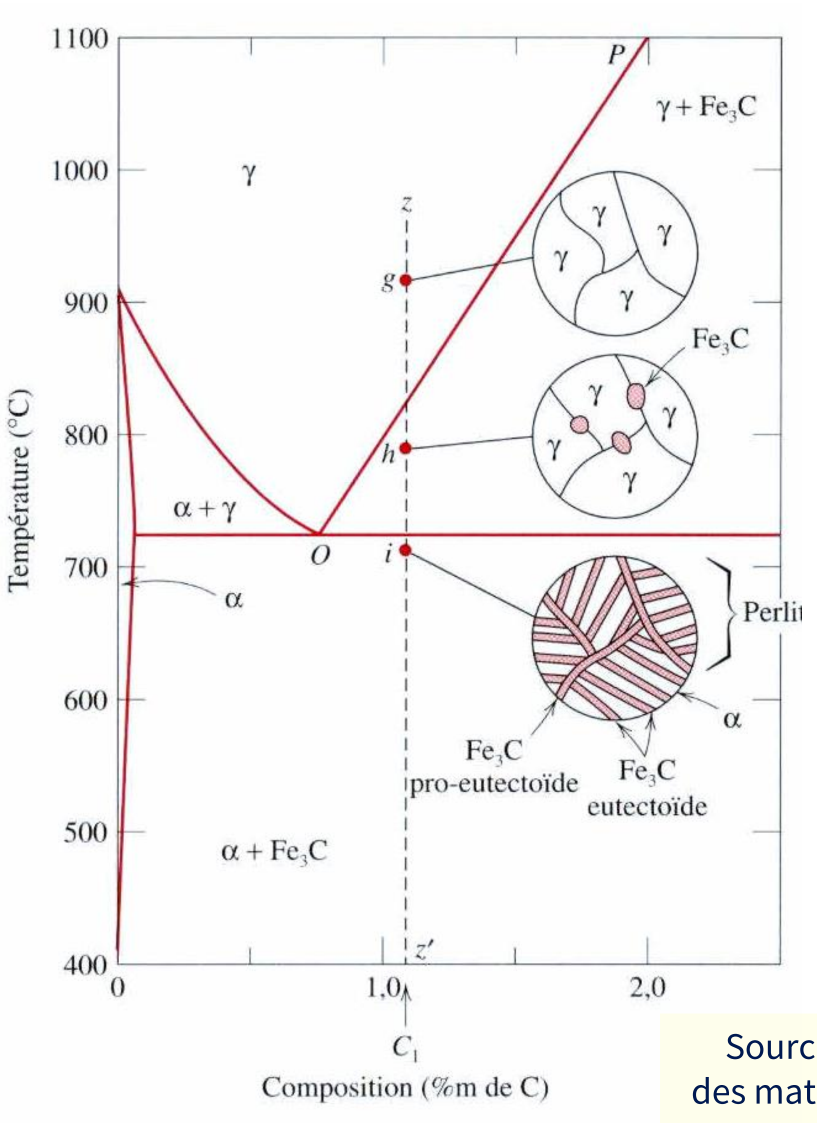
Source: Metallurgia by W. Nicodemi



Source: Science et génie des matériaux, W. Callister

2. Metallurgy - Phases, properties, microstructures

Hypereutectoid steels



Source: Science et génie des matériaux, W. Callister

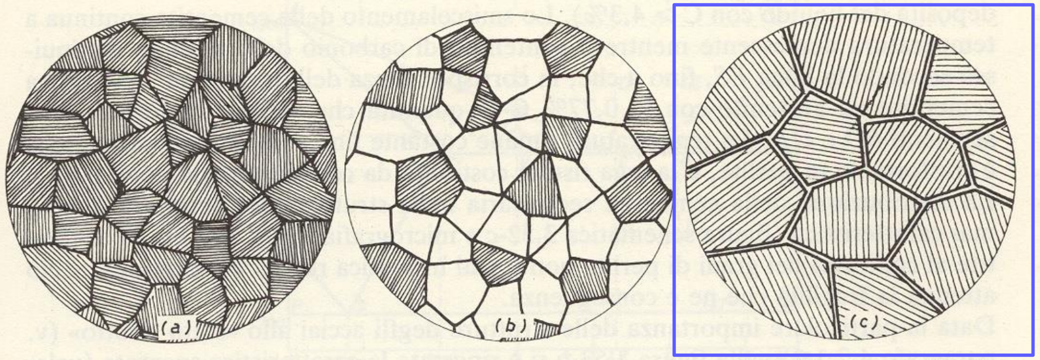
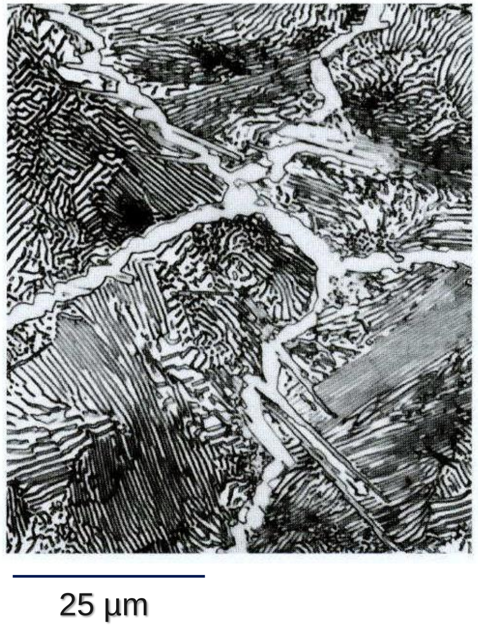


Fig. 3.52 *Rappresentazione schematica delle strutture allo stato ricotto di acciai: a) eutettoide; b) ipo-eutettoide; c) ipereutettoide.*

Source: Metallurgia by W. Nicodemi



Source: Metallurgia
by W. Nicodemi (from Sauveur)

2. Metallurgy - Phases, properties, microstructures

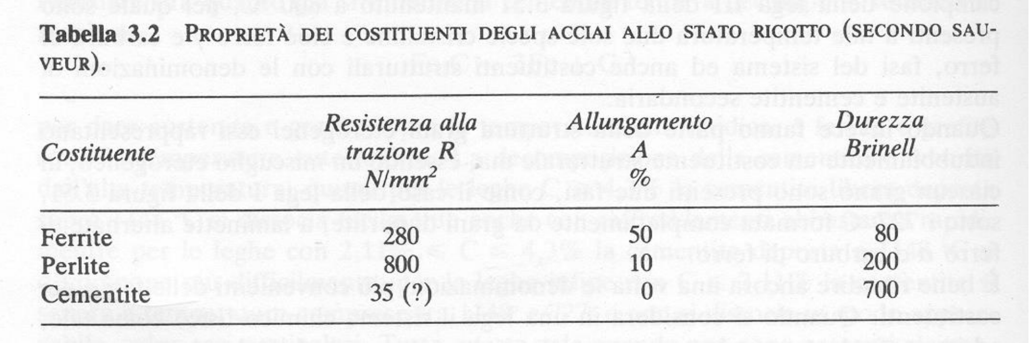
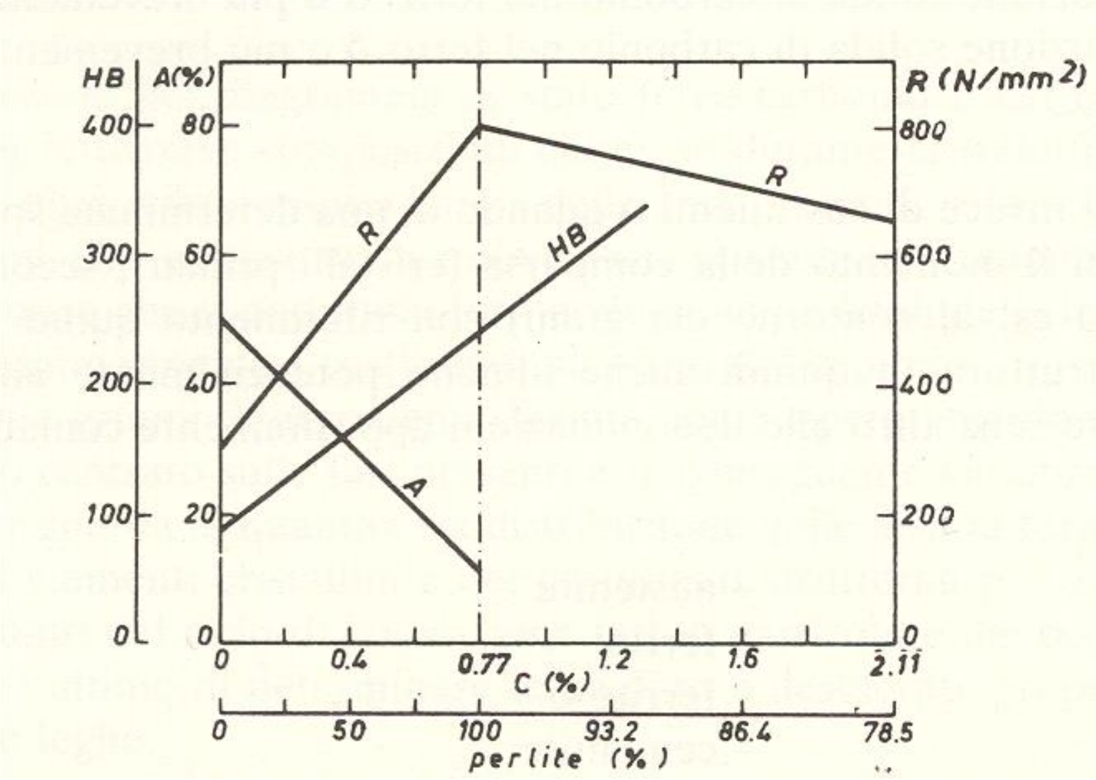
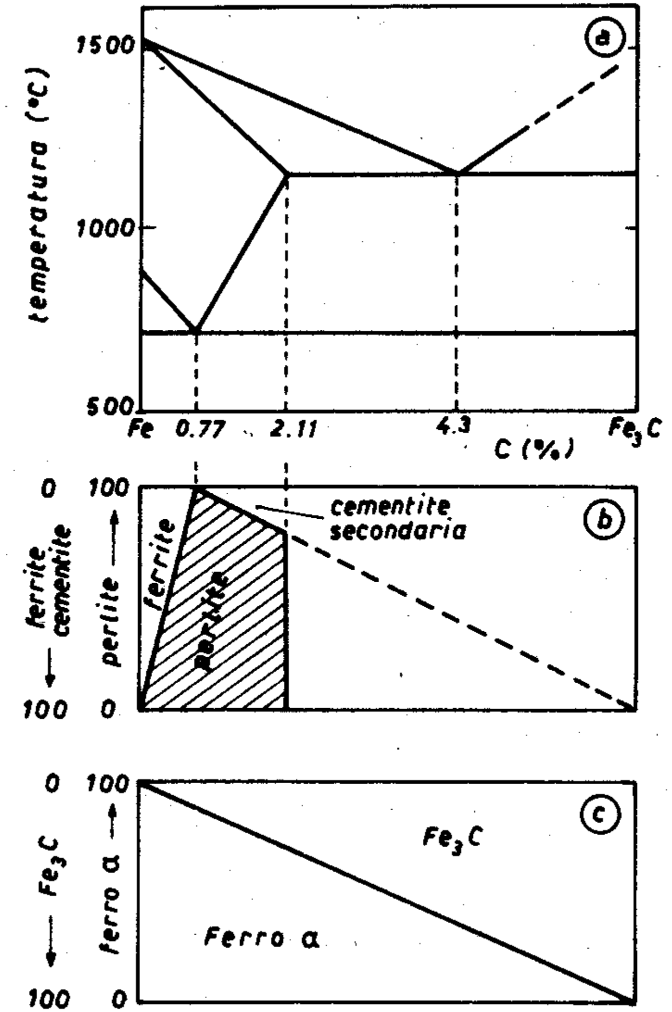


Tabella 3.2 PROPRIETÀ DEI COSTITUENTI DEGLI ACCIAI ALLO STATO RICOTTO (SECONDO SAUVEUR).

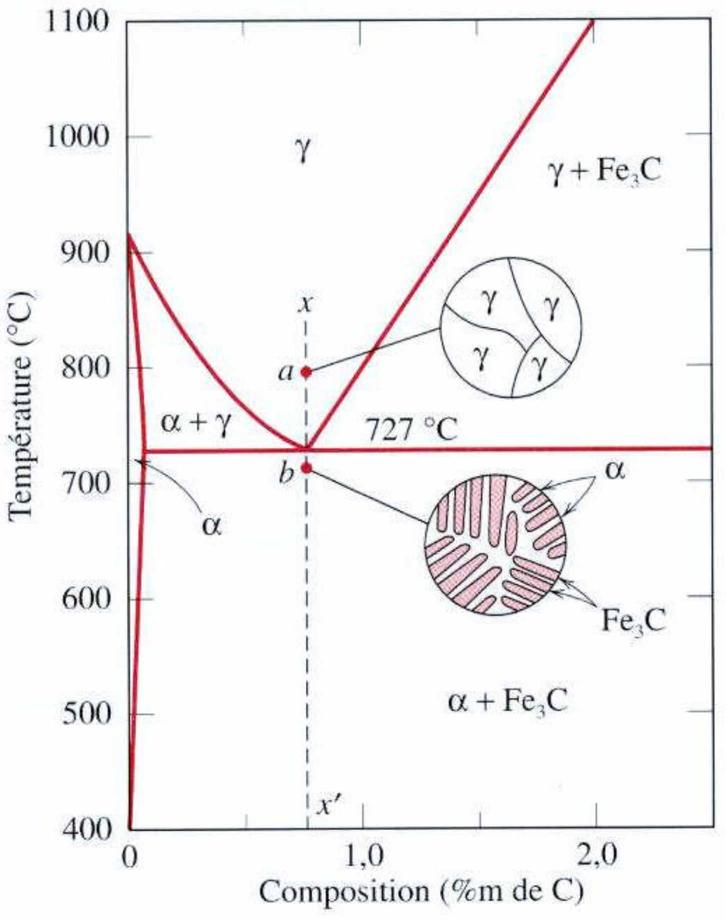
Costituente	*Resistenza alla trazione R* *N/mm²*	*Allungamento A* *%*	*Durezza Brinell*
Ferrite	280	50	80
Perlite	800	10	200
Cementite	35 (?)	0	700

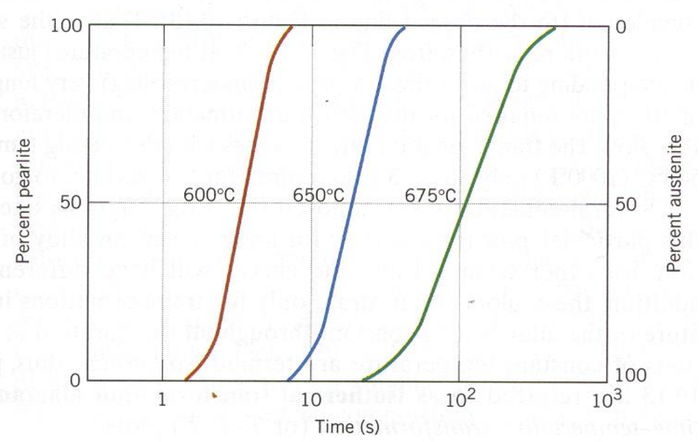




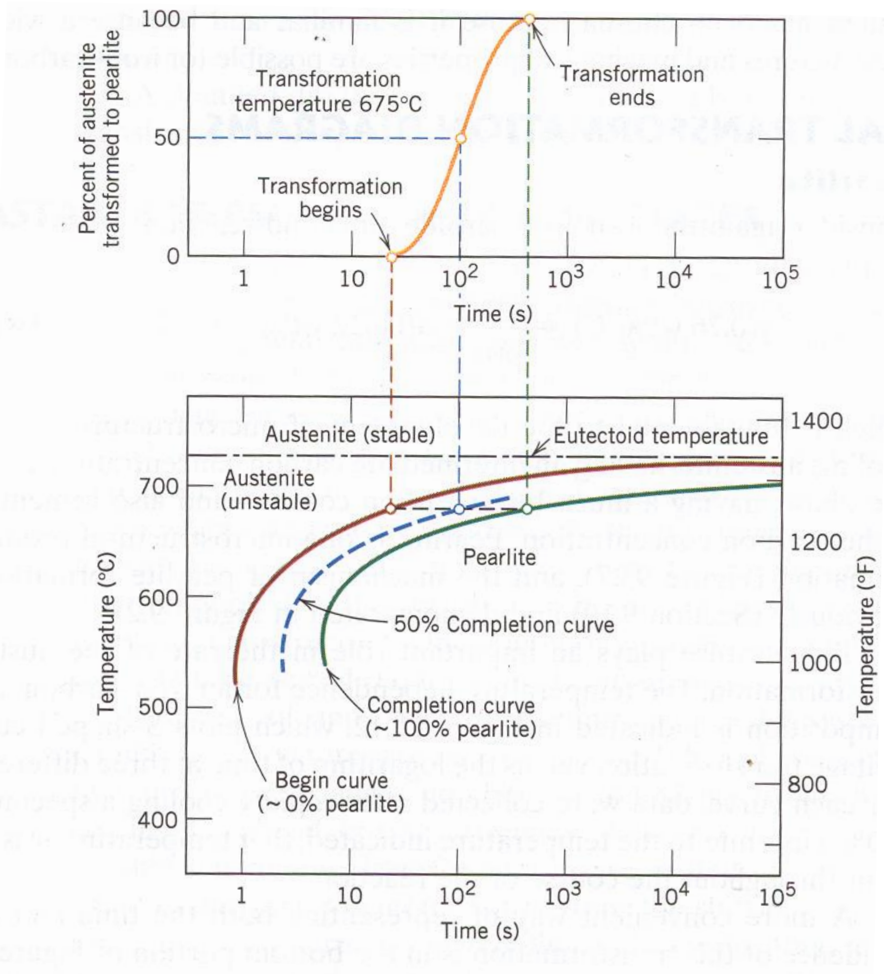
3. Steelmaking practice
Heat treatments and practice

$$\gamma(0.76\text{ wt\% C}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(0.022\text{ wt\% C}) + \mathrm{Fe_3C}(6.70\text{ wt\% C})$$





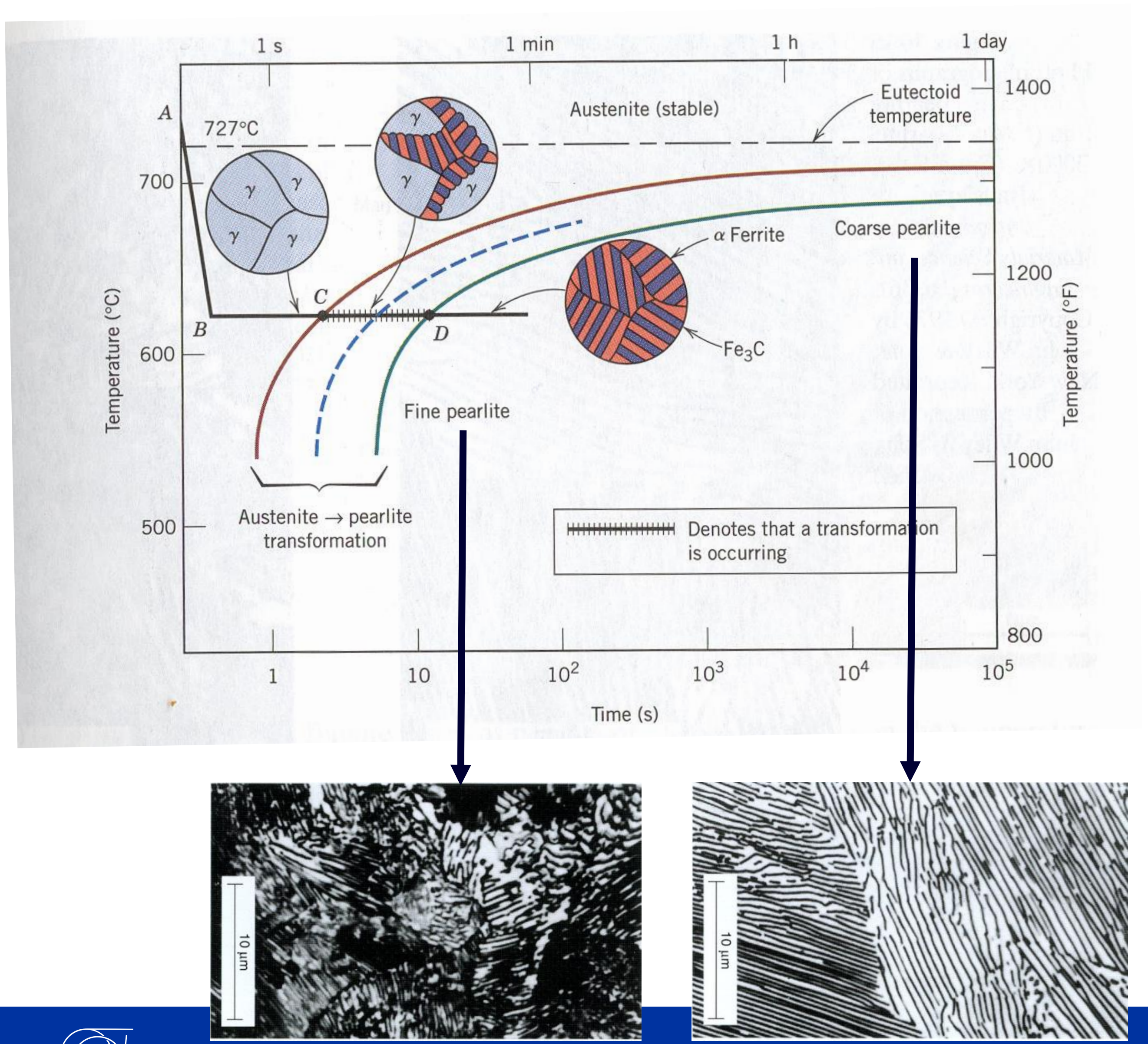
Alloy supercooled to below the eutectoid



Source: Science et génie des matériaux, W. Callister and Materials Science and Engineering: An Introduction, W. Callister and D.G. Rethiwisch (here and similar diagrams)

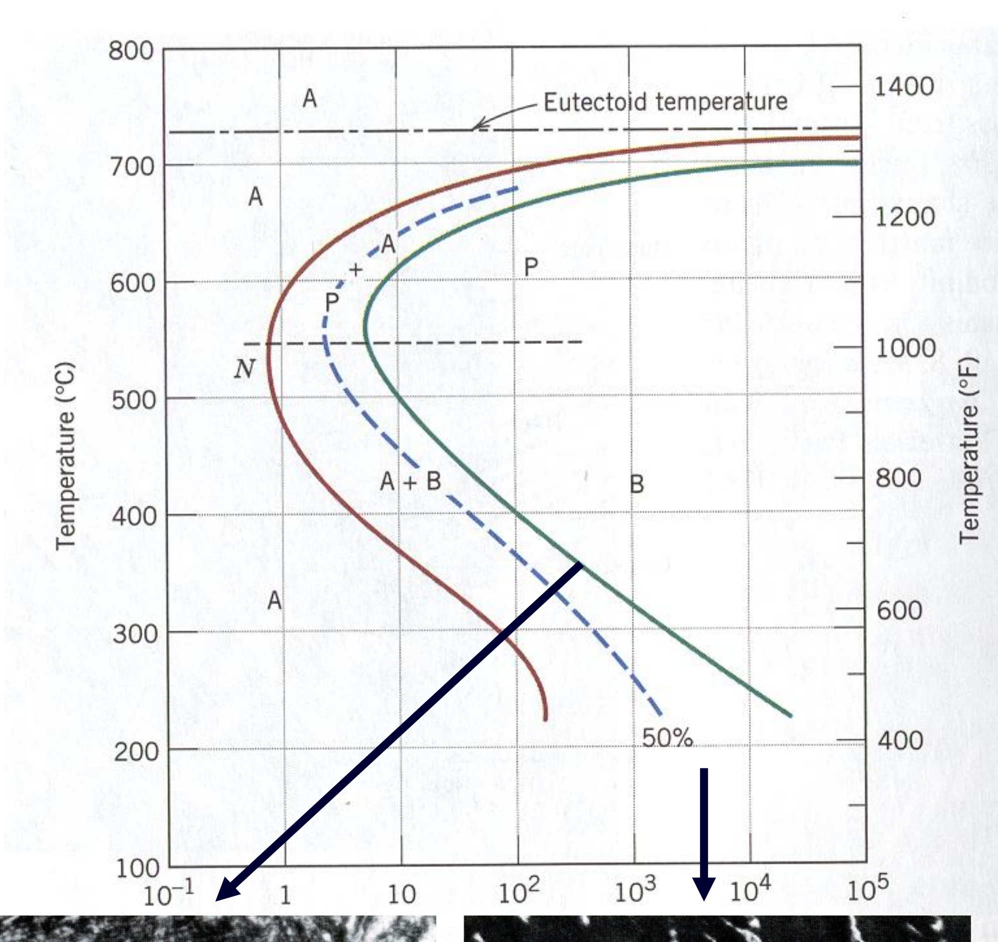
Isothermal heat treatments

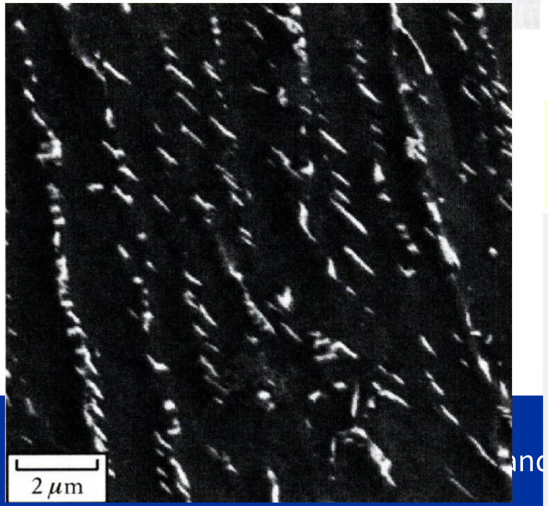
3. Steelmaking practice
Heat treatments and practice

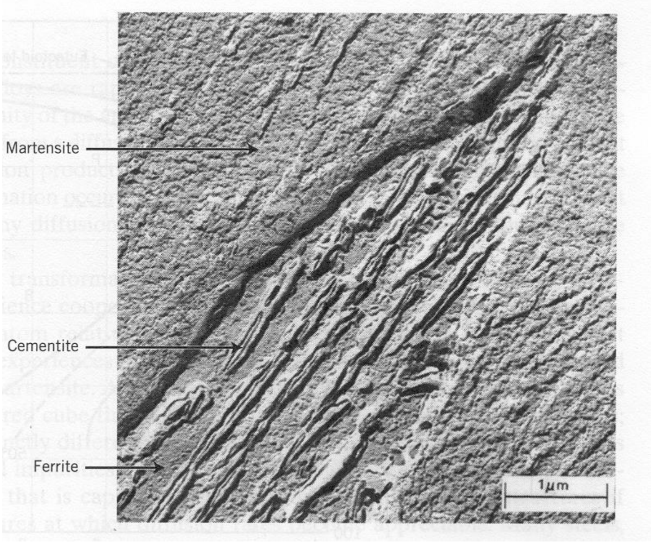


3. Steelmaking practice Heat treatments

Bainitic transformations:
a fine non-lamellar structure, consisting of cementite and dislocation-rich ferrite.







Le superbe et fonctionnel Katana Hunter avec une lame en acier L6-Bainite dans le style Shinogi Zukuri

Source:
Hanwei Forge

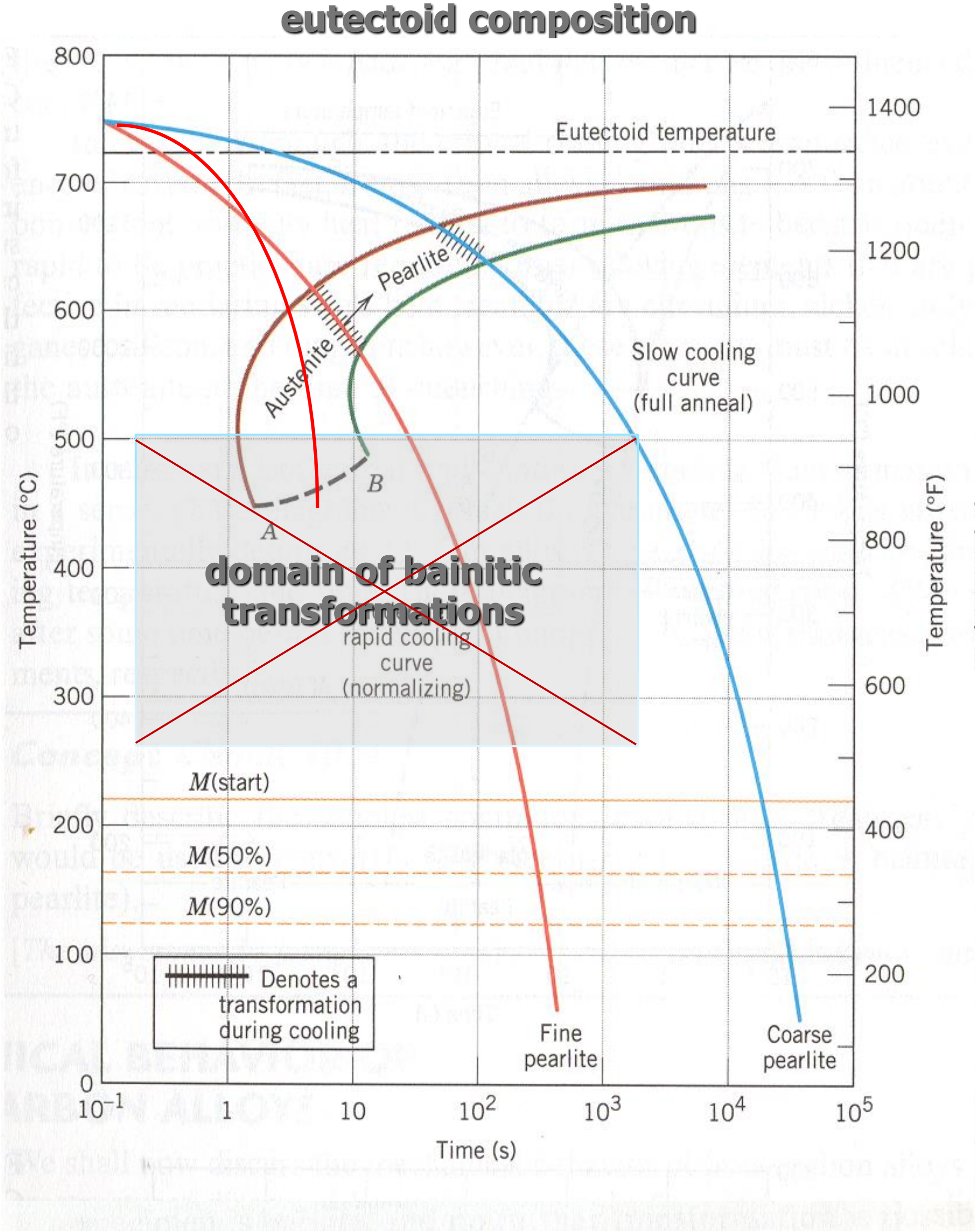
Samurai - Bainite Katana's from Paul Chen

3. Steelmaking practice
Heat treatments

Continuos cooling (CC) transformation diagrams, eutectoid steel

- Isothermal treatments not practical
- CC to RT generally applied
- Isothermal treatment diagrams to be modified
- Reactions delayed for CC conditions →

- Curves shifted to longer times and lower T
- Structures (fine, coarse) controlled by cooling rate



3. Steelmaking practice
Heat treatments

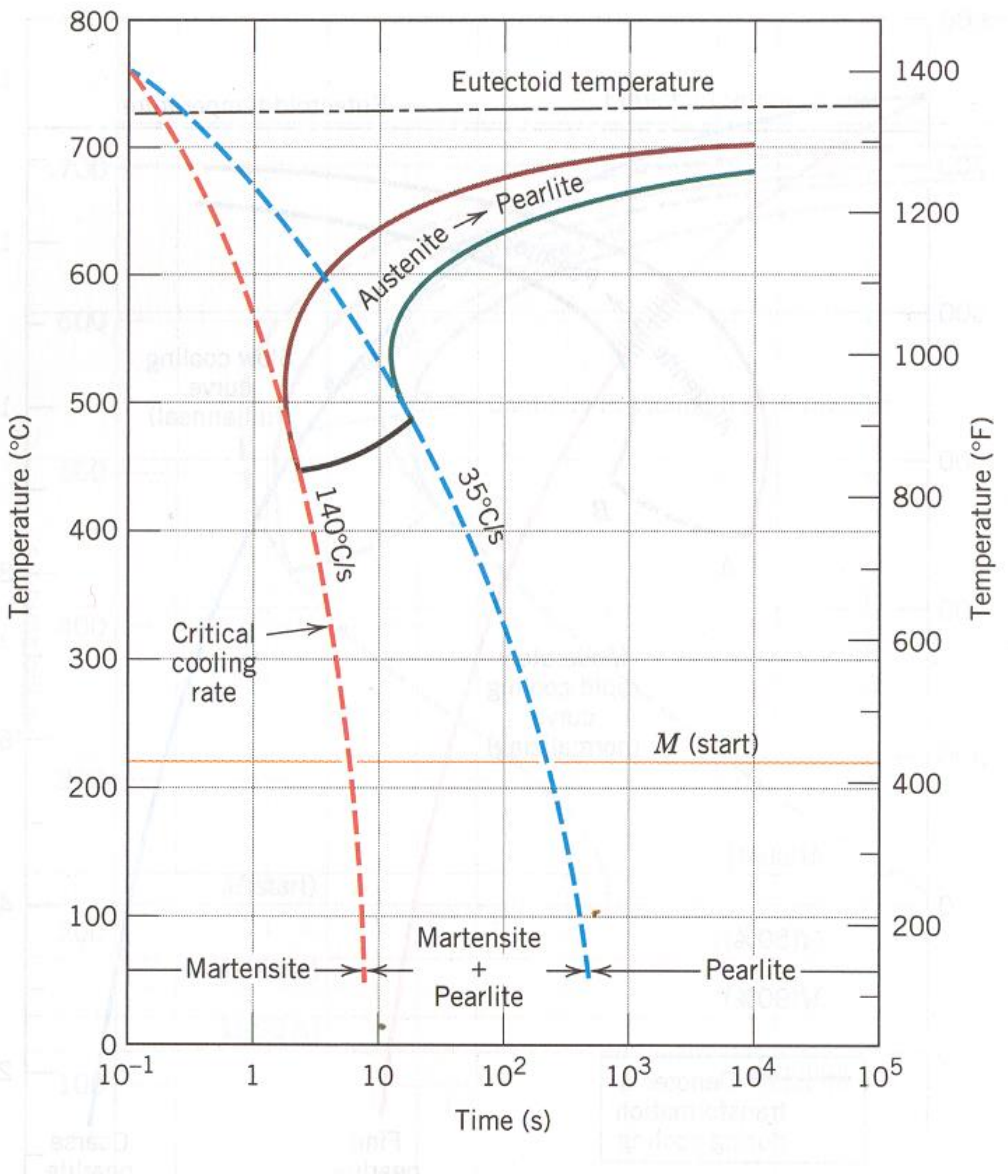
Transformation to martensite, eutectoid steel:

For CC of steel:

- Critical quenching rate exists
- Producing totally martensitic structure
- Missing the "nose" at which pearlite begins

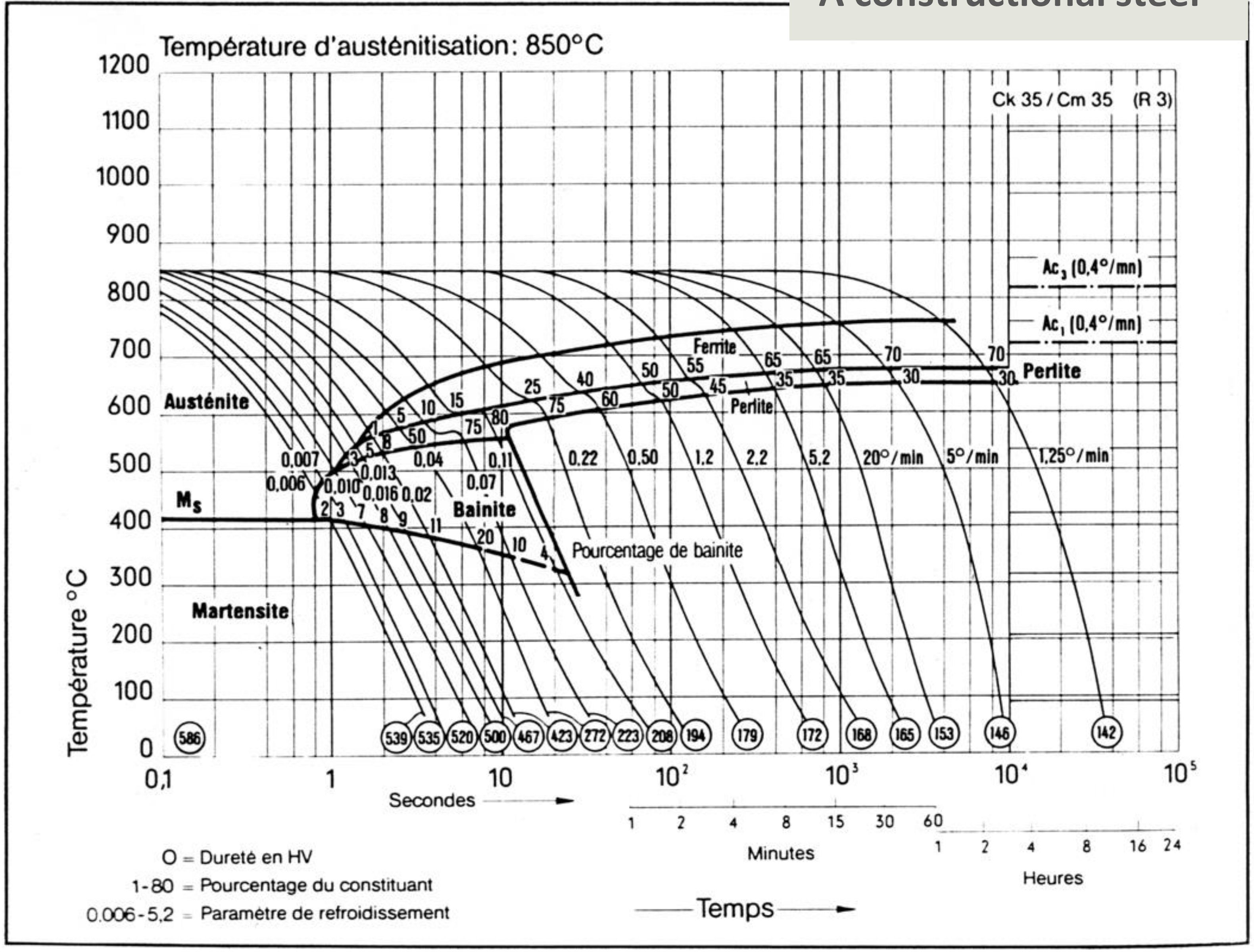
- Very low quenching rates can develop 100 % pearlite

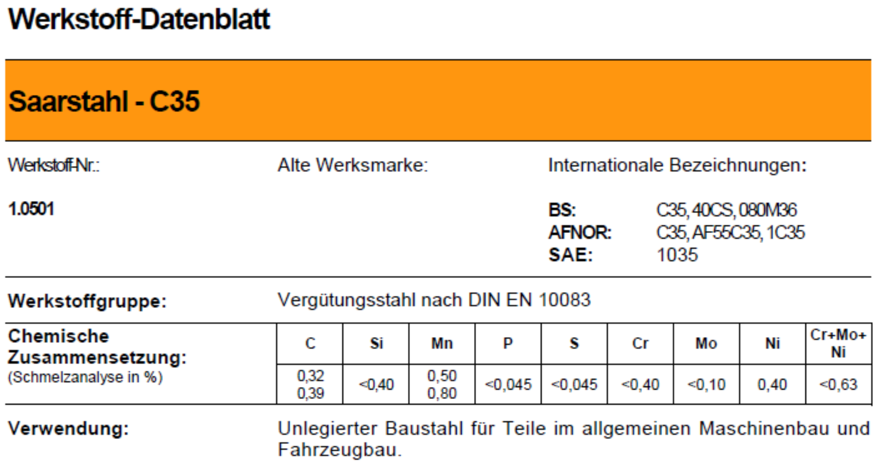
- Intermediate → pearlite + martensite



3. Steelmaking practice
Heat treatments

A constructional steel





Werkstoff-Datenblatt

Saarstahl - C35

Werkstoff-Nr.:	Alte Werksmarke:	Internationale Bezeichnungen:
1.0501		**BS:** C35, 40CS, 080M36 **AFNOR:** C35, AF55C35, 1C35 **SAE:** 1035

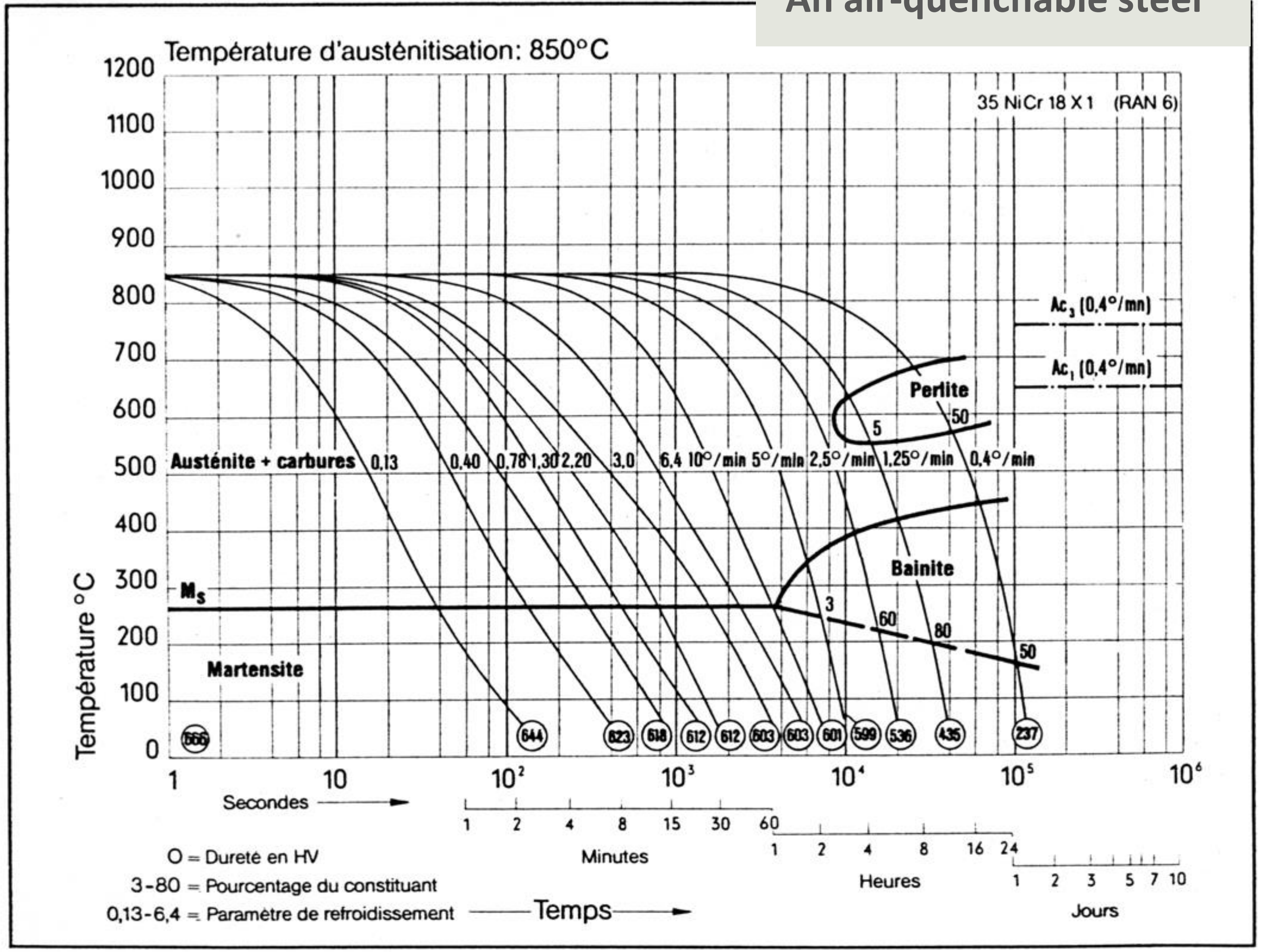
Werkstoffgruppe: Vergütungsstahl nach DIN EN 10083

Chemische Zusammensetzung: (Schmelzanalyse in %)	C	Si	Mn	P	S	Cr	Mo	Ni	Cr+Mo+Ni
	0,32 0,39	<0,40	0,50 0,80	<0,045	<0,045	<0,40	<0,10	0,40	<0,63

Verwendung: Unlegierter Baustahl für Teile im allgemeinen Maschinenbau und Fahrzeugbau.

3. Steelmaking practice
Heat treatments

An air-quenchable steel



Saarstahl-35 NiCr 18

No allemand	–
AFNOR	**40 NC 17**
Ancienne désignation	**RAN 6**

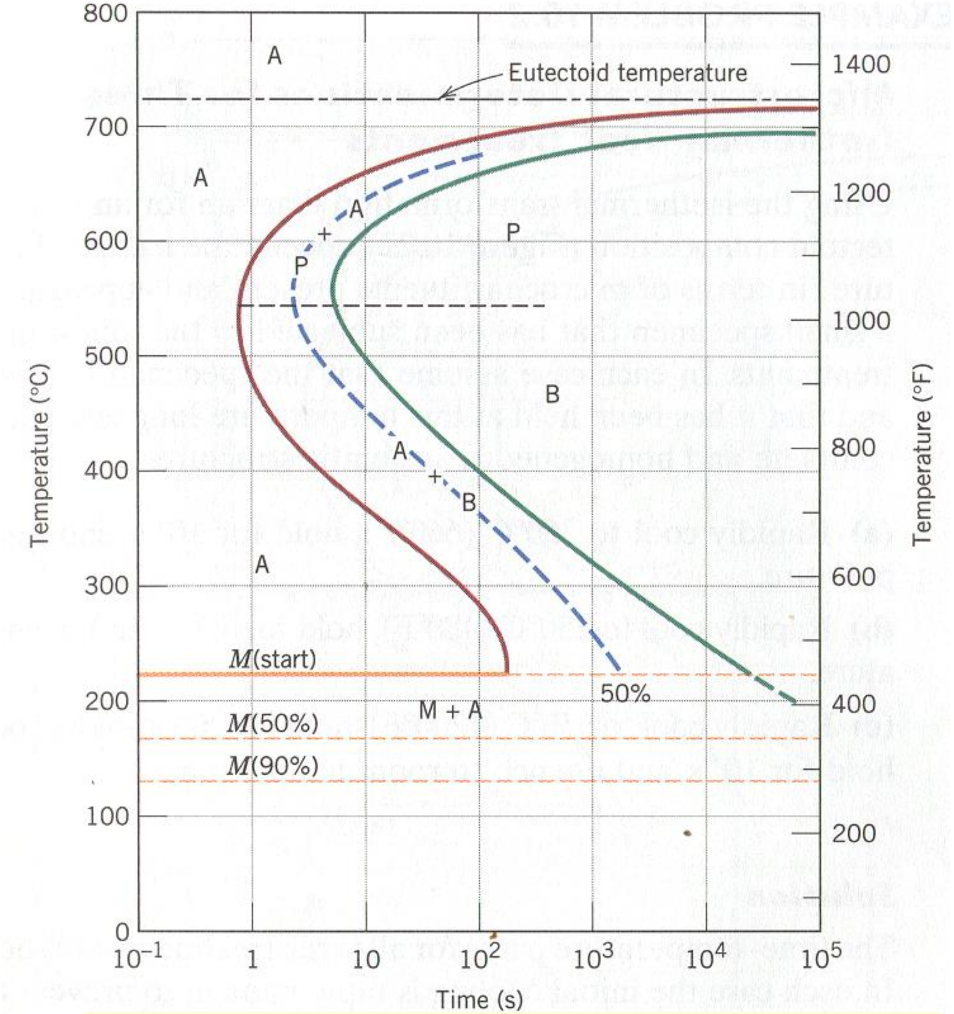
Composition chimique

(moyenne en %)

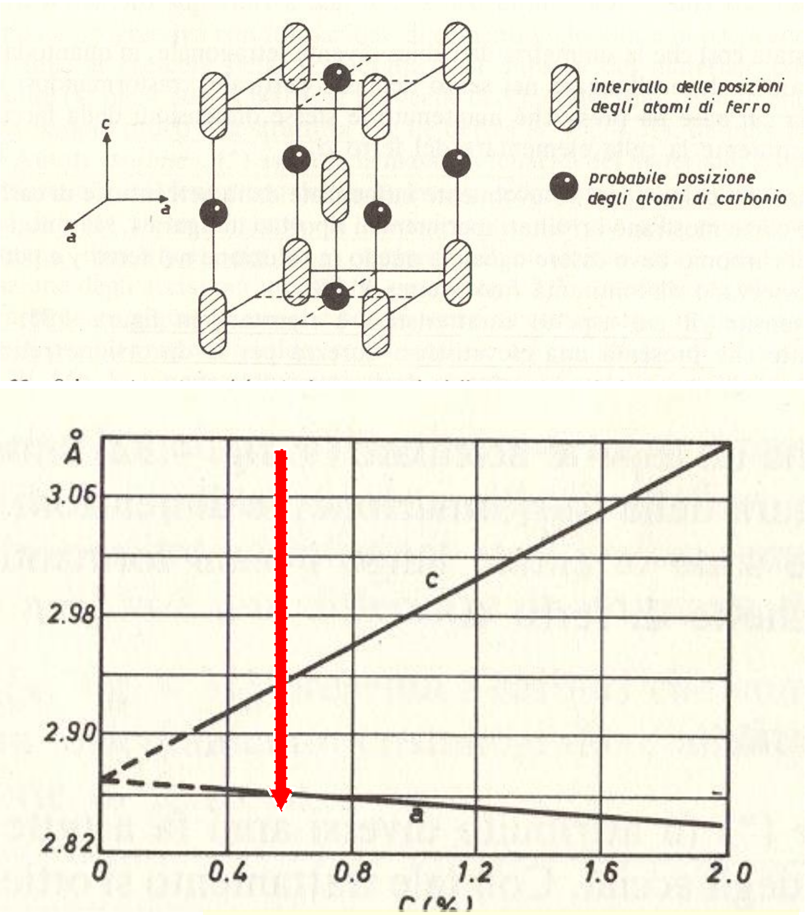
C	0,40
Si	0,25
Mn	0,40
Cr	1,65
Ni	4,35

Martensitic transformations

3. Steelmaking practice - Heat treatments

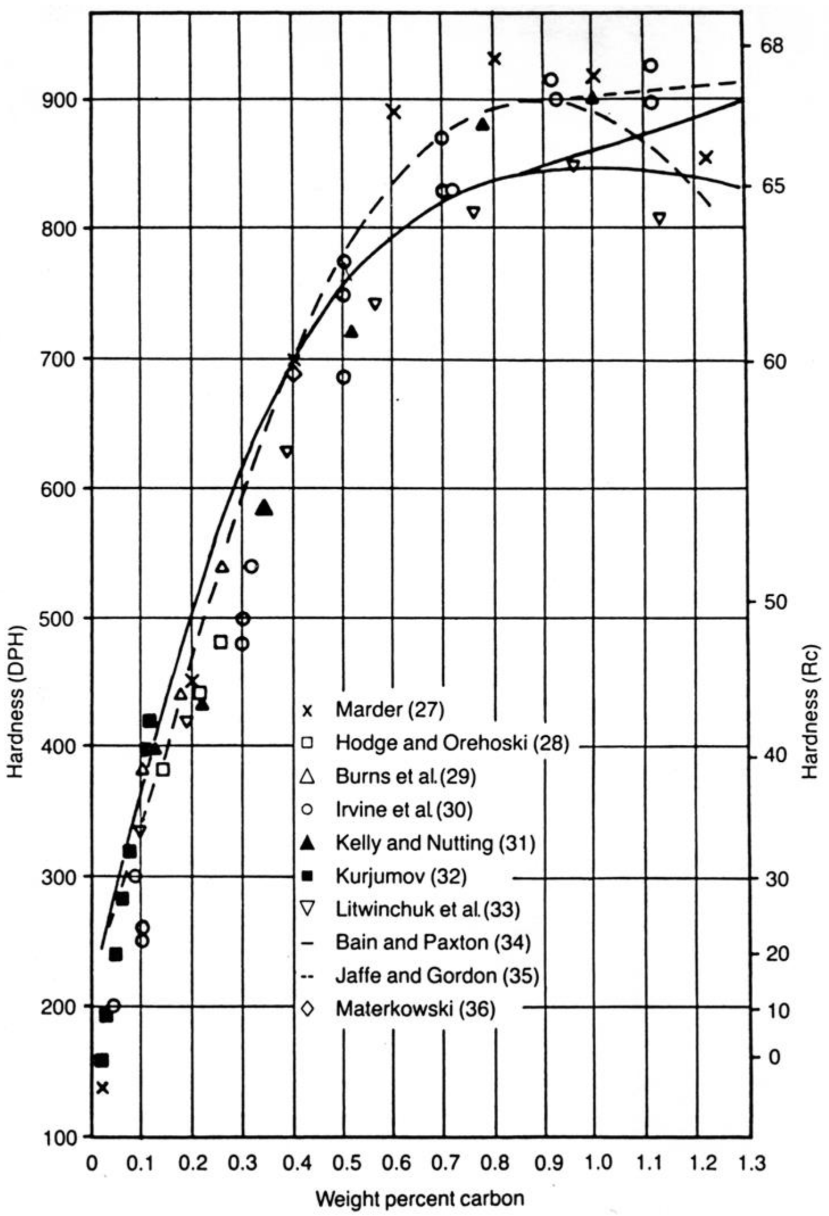


Source: Science et génie des matériaux, W. Callister



Source: Metallurgia by W. Nicodemi

3. Steelmaking practice - Heat treatments

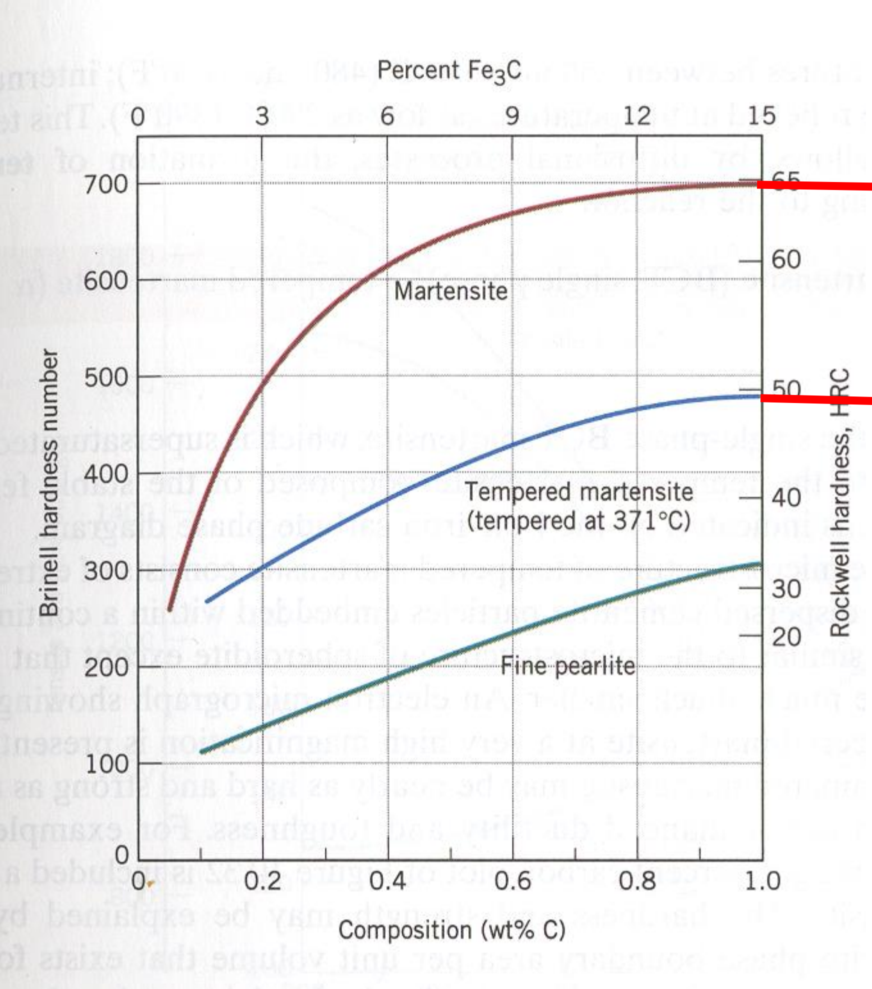


Applicable to as-quenched structures:

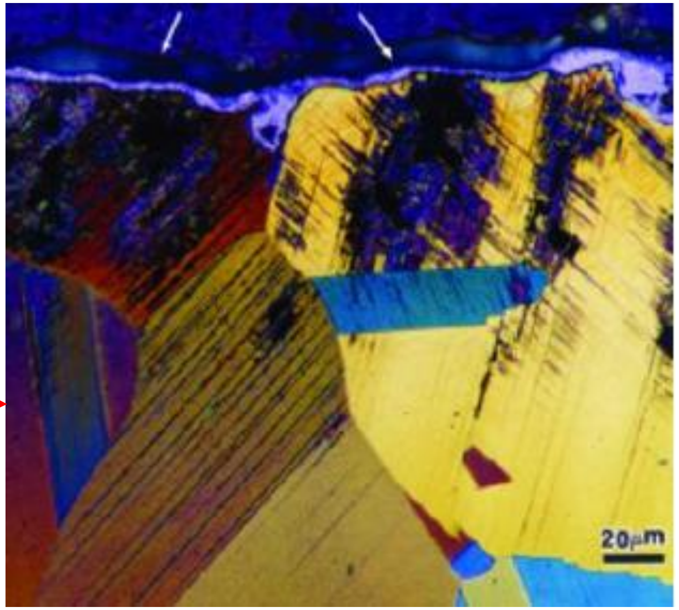
- C confers hardness
- Excessive hardness → brittleness
- Tempering applicable

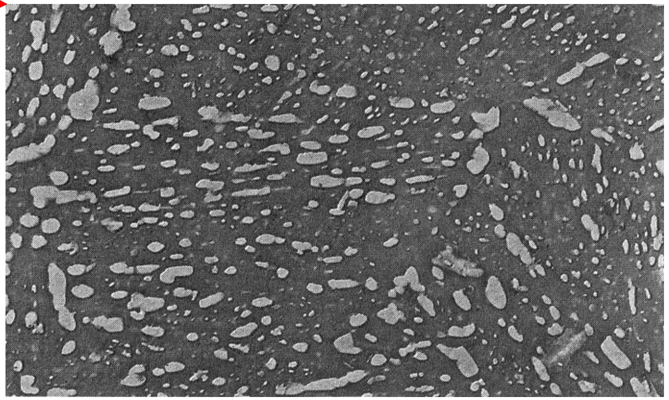
Martensitic transformations

3. Steelmaking practice
Heat treatments

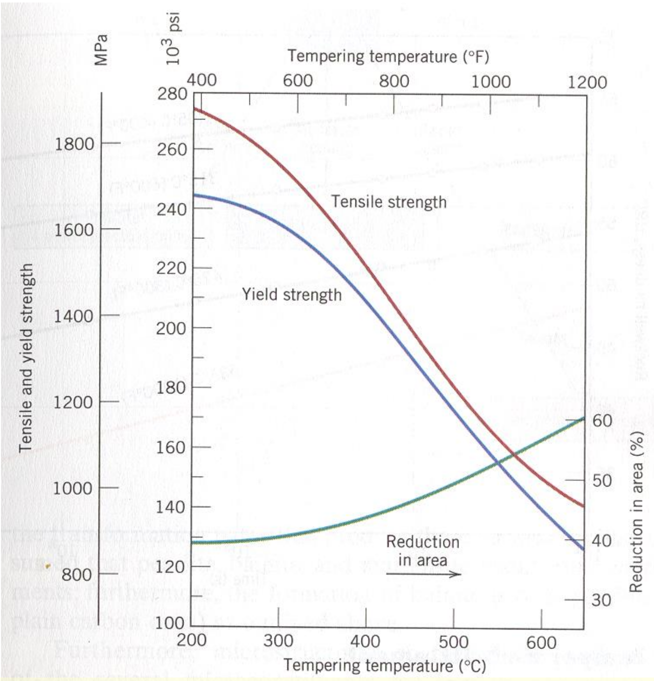


Hardness can be decreased by time and T (tempering)

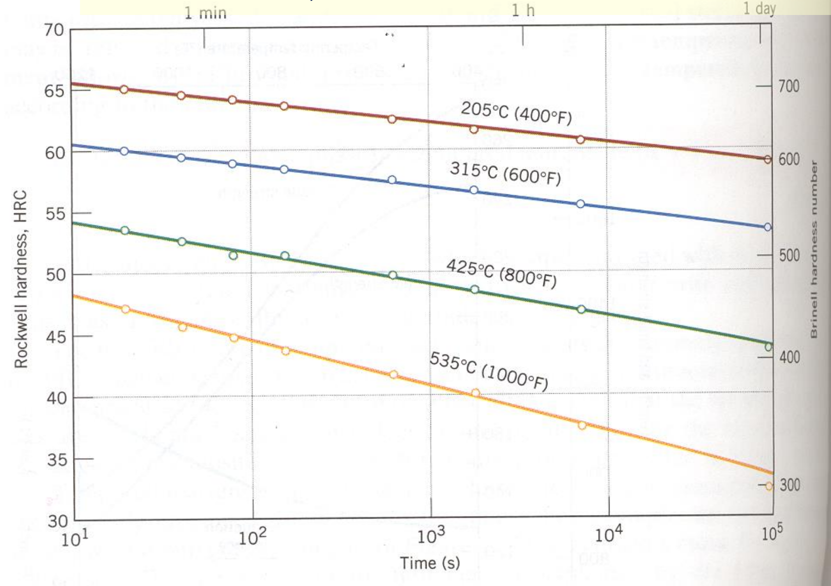




Tempered martensite reverts back to ferrite and cementite

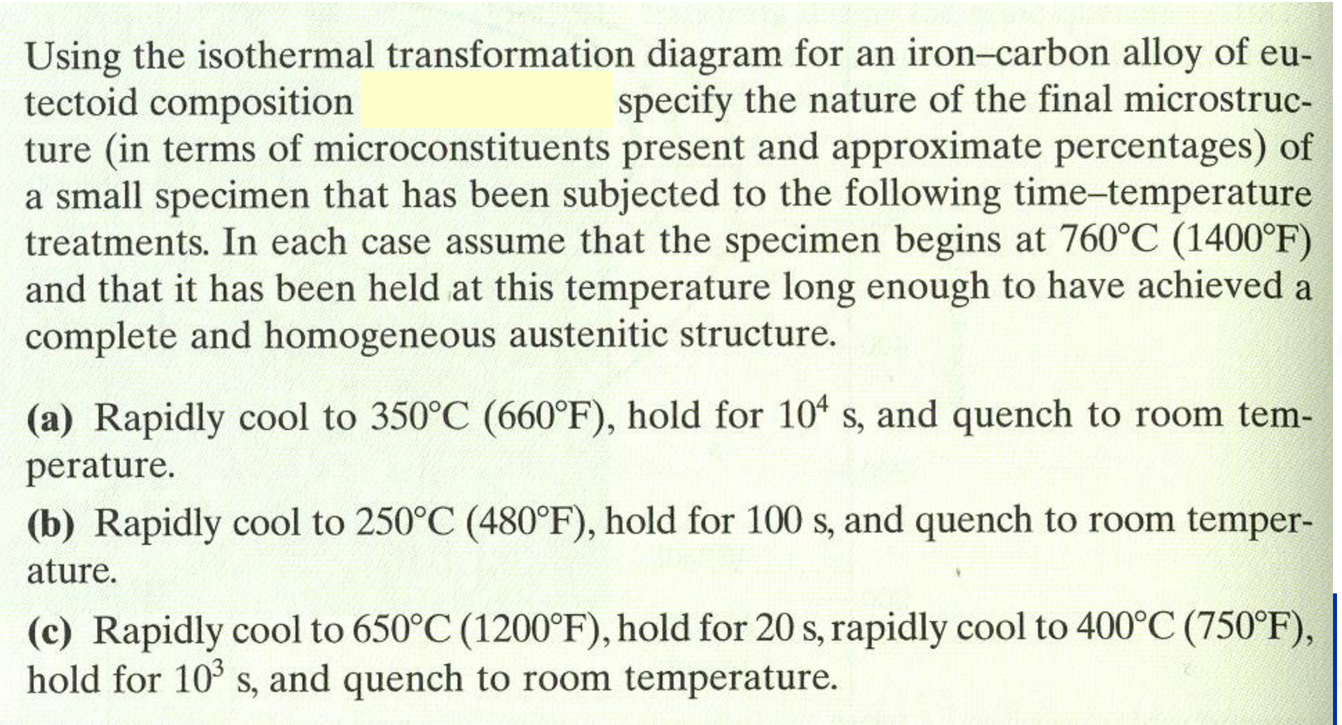


Source: Materials Science and Engineering: An Introduction, W. Callister and D.G. Rethiwisch



3. Steelmaking practice
Heat treatments - exercice

Which one creates a Kanata's sword?
(a), (b) or (c)?

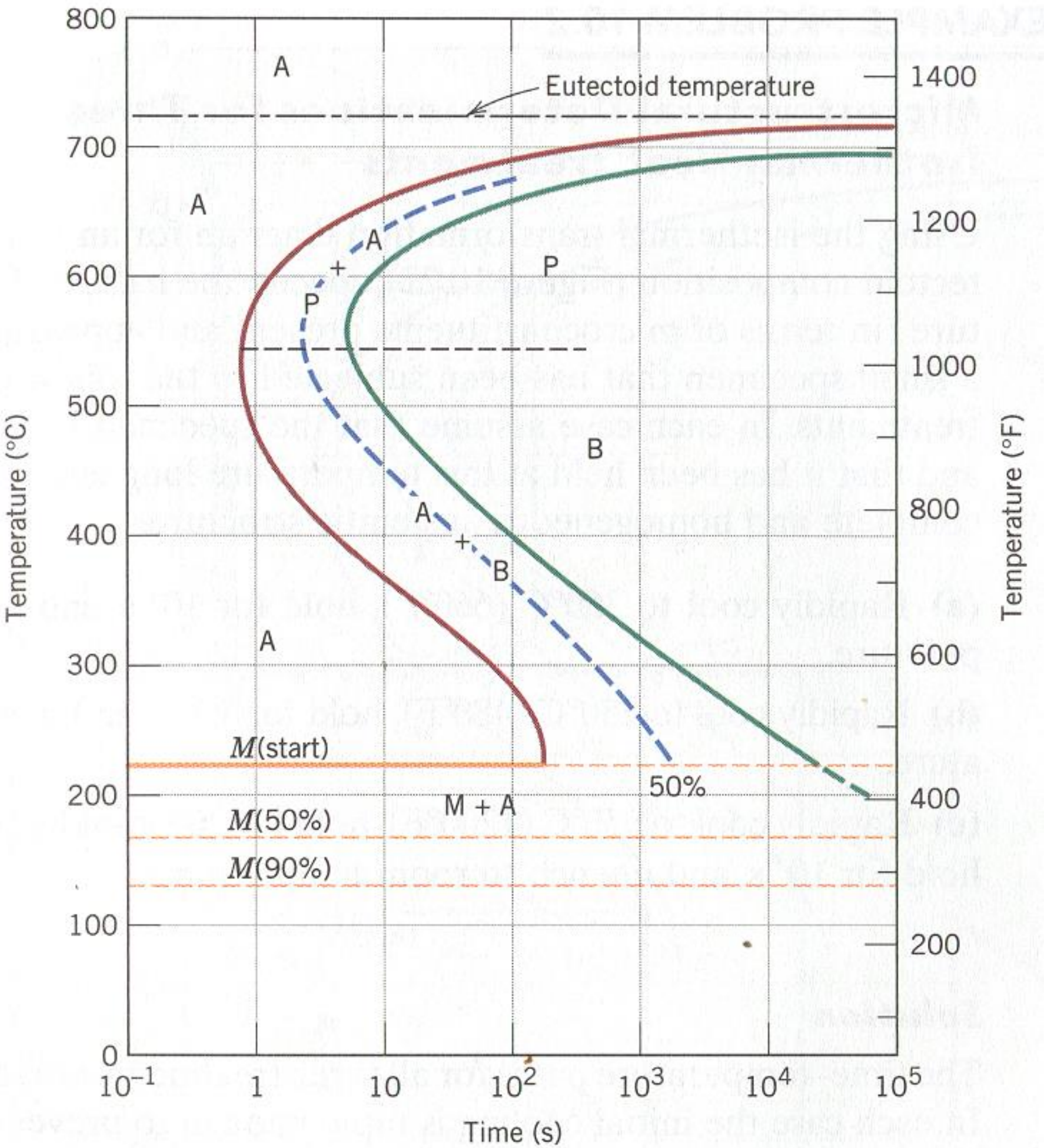


Using the isothermal transformation diagram for an iron–carbon alloy of eutectoid composition [redacted] specify the nature of the final microstructure (in terms of microconstituents present and approximate percentages) of a small specimen that has been subjected to the following time–temperature treatments. In each case assume that the specimen begins at 760°C (1400°F) and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.

(a) Rapidly cool to 350°C (660°F), hold for 10^4 s, and quench to room temperature.

(b) Rapidly cool to 250°C (480°F), hold for 100 s, and quench to room temperature.

(c) Rapidly cool to 650°C (1200°F), hold for 20 s, rapidly cool to 400°C (750°F), hold for 10^3 s, and quench to room temperature.



3. Steelmaking practice
Heat treatments

"Heat treatment of steel"

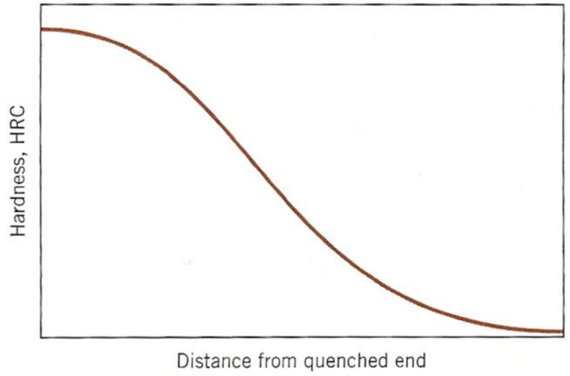
Ordinarily intended for producing martensitic steels

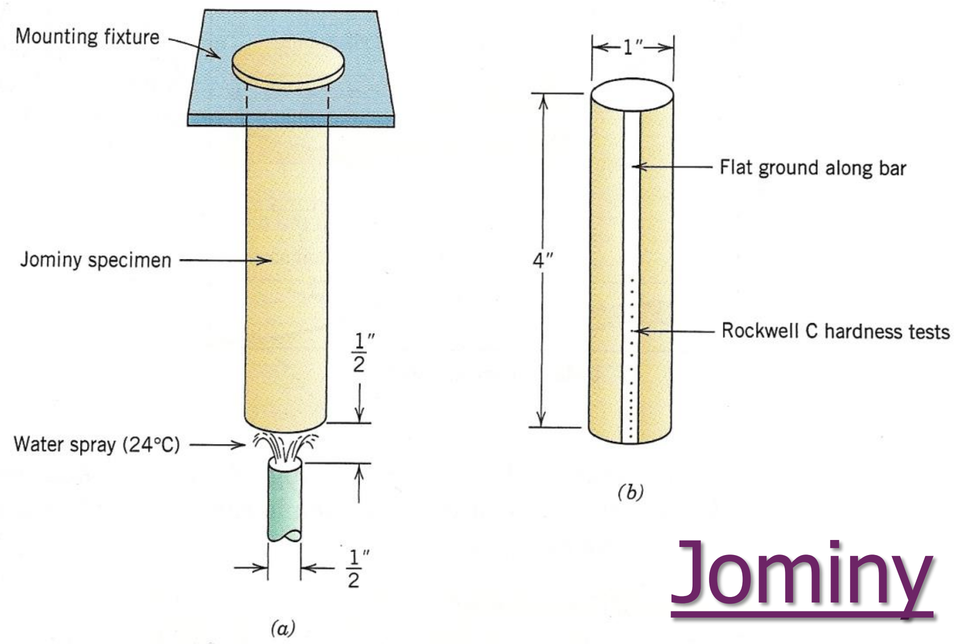
Treatable steels referred as:

"Vergütungsstähle"
"Aciers d'amélioration"
"Heat treatable steels"
"Acciai da bonifica"

Successful treatment depends from:

- Steel composition
- Type and character of quenching medium
- Size and shape of the specimen →
- Hardenability

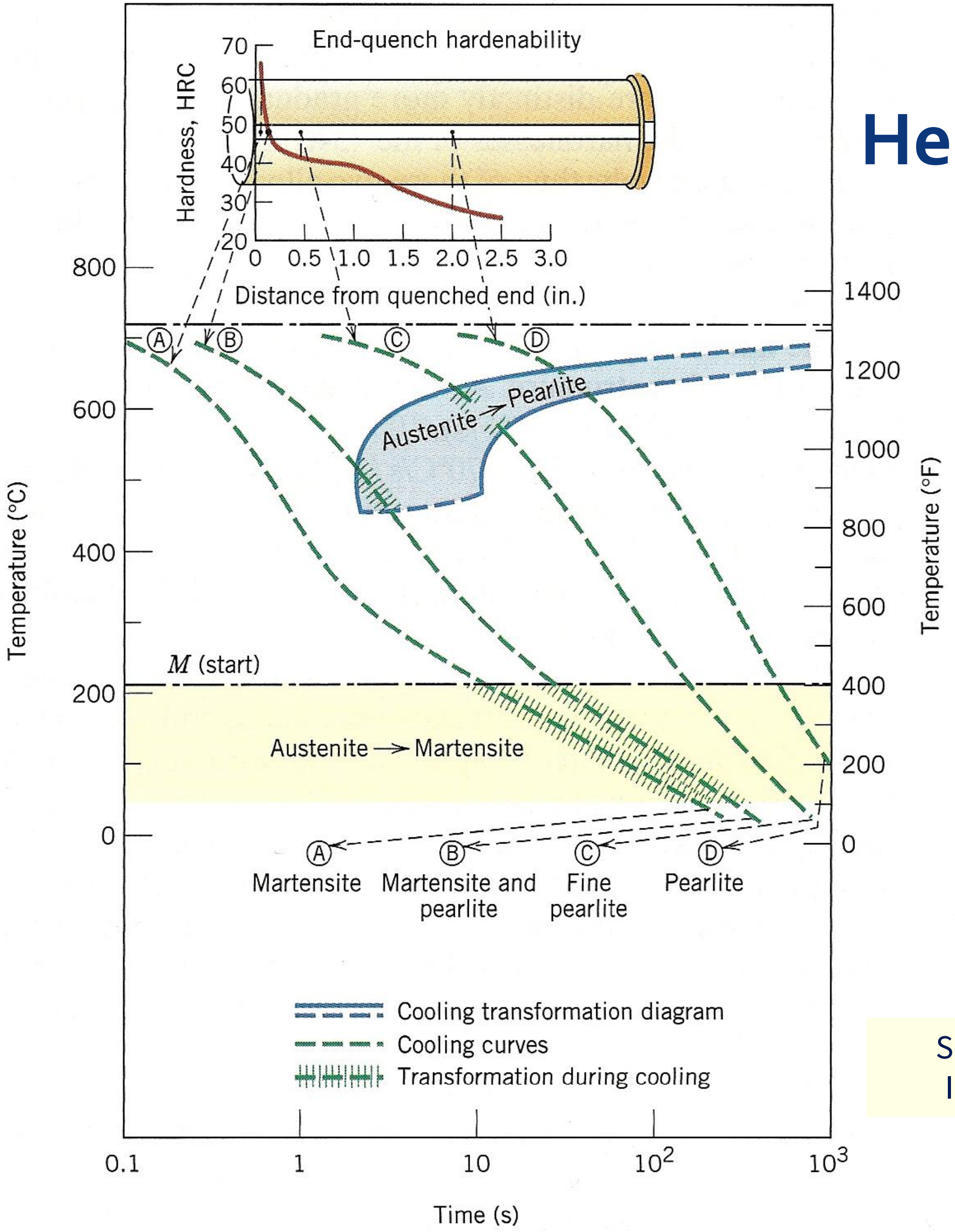




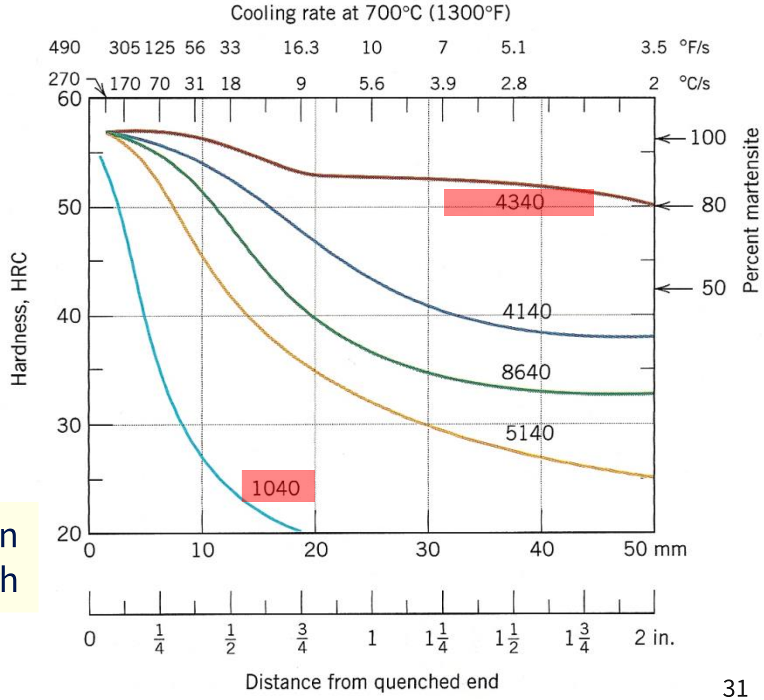
Jominy

3. Steelmaking practice

Heat treatments – Jominy test

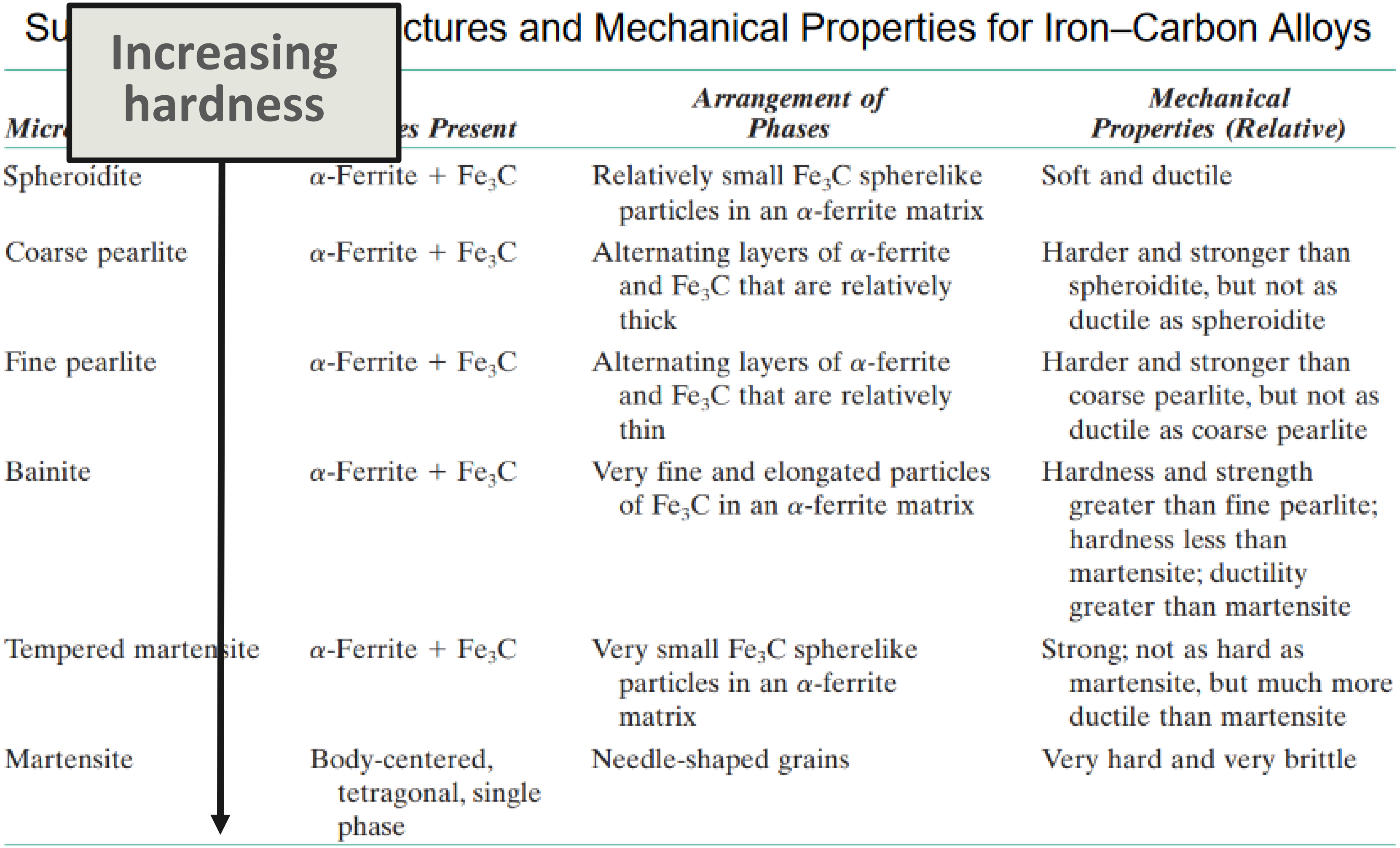


Hardenability curves for five different steel alloys, each containing 0.4 wt% C. Approximate alloy compositions (wt%) are as follows: 4340–1.85 Ni, 0.80 Cr, and 0.25 Mo; 4140–1.0 Cr and 0.20 Mo; 8640–0.55 Ni, 0.50 Cr, and 0.20 Mo; 5140–0.85 Cr; and 1040 is an unalloyed steel. (Adapted from figure furnished courtesy Republic Steel Corporation.)



Source: Materials Science and Engineering: An Introduction, W. Callister and D.G. Rethiwisch

3. Steelmaking practice - Tailoring the properties of heat treatable steels



Increasing hardness

Su ctures and Mechanical Properties for Iron–Carbon Alloys

Micr	*es Present*	*Arrangement of Phases*	*Mechanical Properties (Relative)*
Spheroidite	α-Ferrite + Fe_3C	Relatively small Fe_3C spherelike particles in an α-ferrite matrix	Soft and ductile
Coarse pearlite	α-Ferrite + Fe_3C	Alternating layers of α-ferrite and Fe_3C that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	α-Ferrite + Fe_3C	Alternating layers of α-ferrite and Fe_3C that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	α-Ferrite + Fe_3C	Very fine and elongated particles of Fe_3C in an α-ferrite matrix	Hardness and strength greater than fine pearlite; hardness less than martensite; ductility greater than martensite
Tempered martensite	α-Ferrite + Fe_3C	Very small Fe_3C spherelike particles in an α-ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered, tetragonal, single phase	Needle-shaped grains	Very hard and very brittle

Source: Materials Science and Engineering, An Introduction by William D. Callister Jr. & David G. Rethwisch

4. Case study: ductile to brittle transition

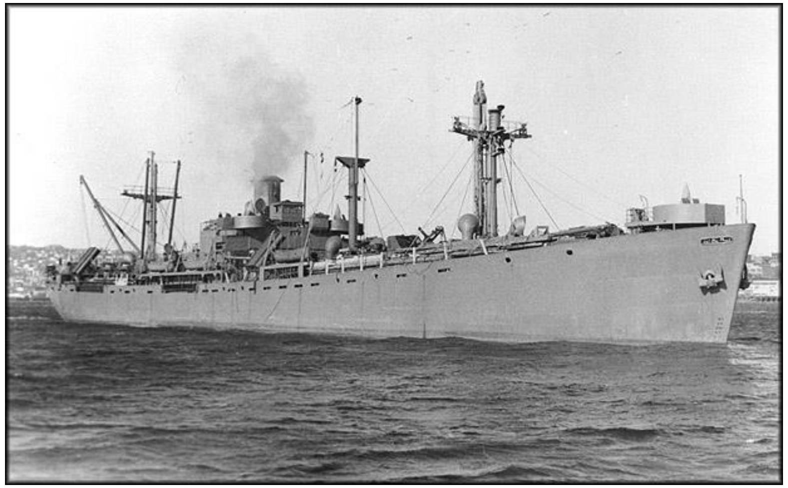
Pictures from Earl R. Parker, Brittle Behavior of Engineering Structures, National Academy of Sciences, National Research Council, John Wiley & Sons, New York, 1957

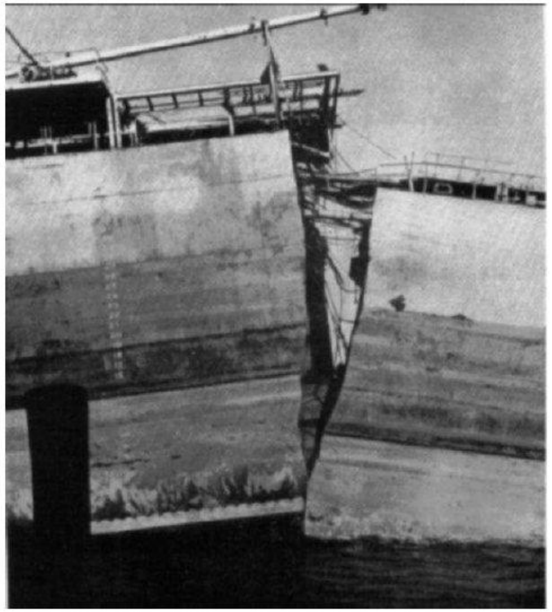
Predominantly C-Mn steels

- Ferrite-pearlite microstructures
- Plates and sections
- Up to several hundred mm thick (HR)
- Includes also low-alloy grades quenched and tempered in order to provide yield strengths up to about 700 MPa
- Weldability: a key issue since the 40ies →

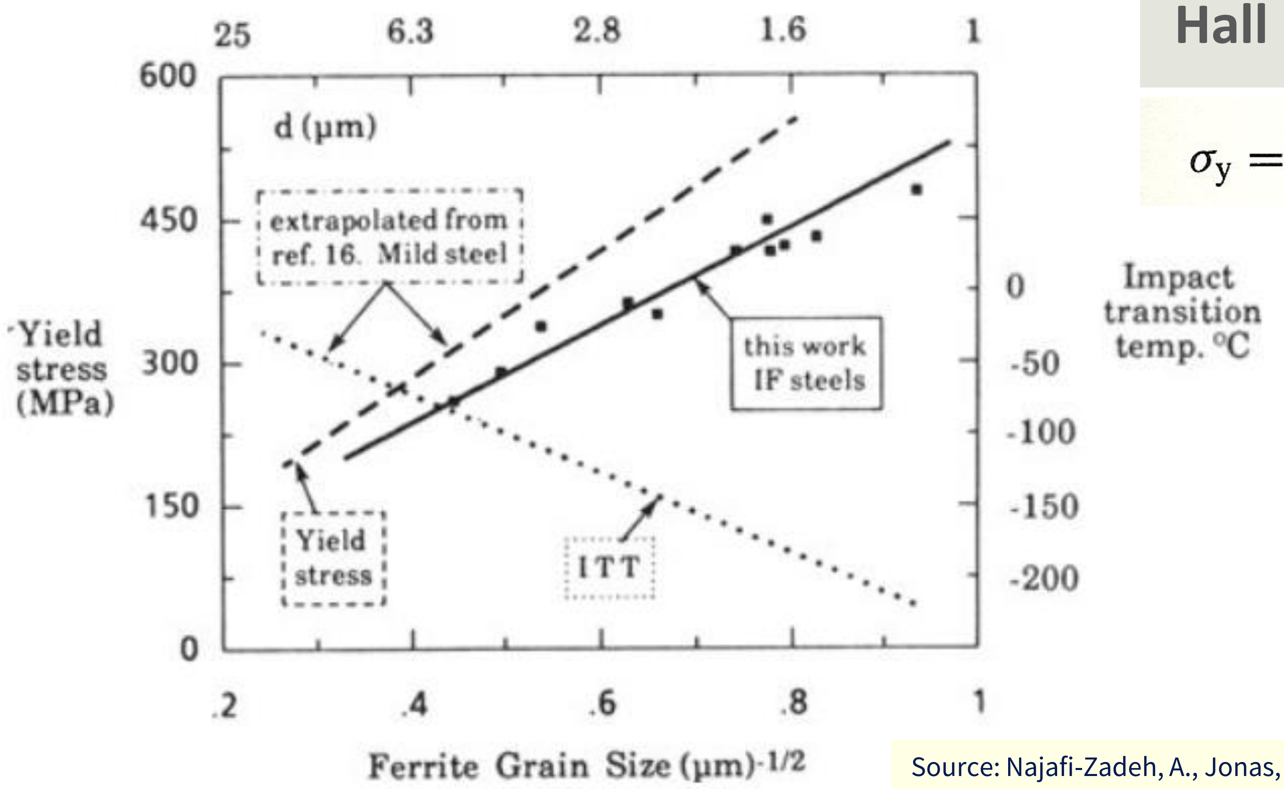
Strength, ductility, toughness

liberty_ships





4. Case study: ductile to brittle transition



Hall & Petch relationship

$$\sigma_y = \sigma_i + k' \text{ (\% alloy) } + k_y d^{-\frac{1}{2}}$$

Source: Najafi-Zadeh, A., Jonas, J.J. & Yue, S. Grain refinement by dynamic recrystallization during the simulated warm-rolling of interstitial free steels. Metall Trans A 23, 2607–2617 (1992) https://doi.org/10.1007/BF02658064

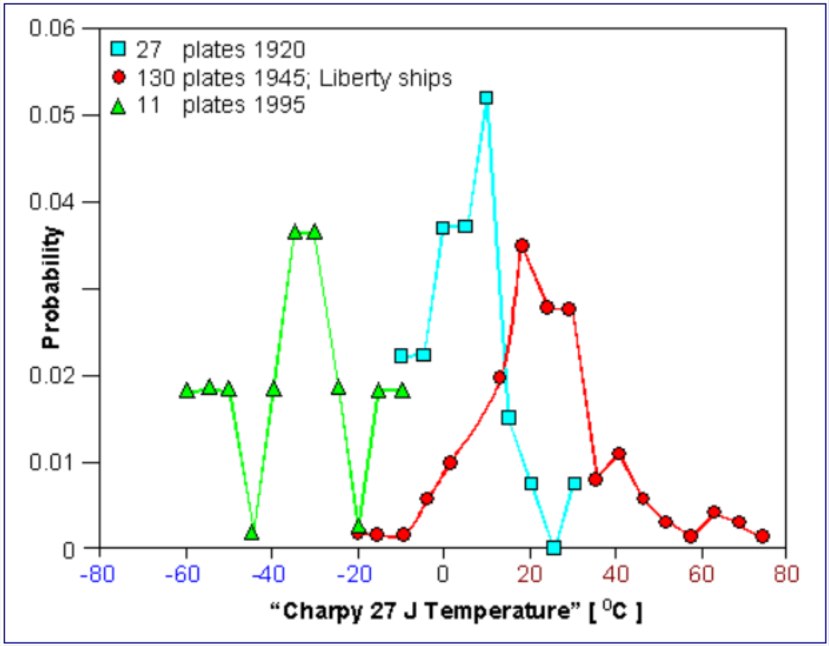
DBTT

$$\text{YS (N/mm}^2) = 53.9 + 32.3\% \text{ Mn} + 83.2\% \text{ Si} + 354\% \text{ N}_f + 17.4d^{-\frac{1}{2}}$$

$$\text{TS (N/mm}^2) = 294 + 27.7\% \text{ Mn} + 83.2\% \text{ Si} + 3.85\% \text{ pearlite} + 7.7d^{-\frac{1}{2}}$$

$$\text{ITT (°C)} = -19 + 44\% \text{ Si} + 700\surd(\%\text{N}_f) + 2.2\% \text{ pearlite} - 11.5d^{-\frac{1}{2}}$$

where d is the mean ferrite grain size in mm and N_f the free (soluble) nitrogen.



Charpy test data from ship steel including plate from Liberty ships

Source: The paper of J.D.G. Sumpter, J.S. Kent 1)

4. Case study: ductile to brittle transition

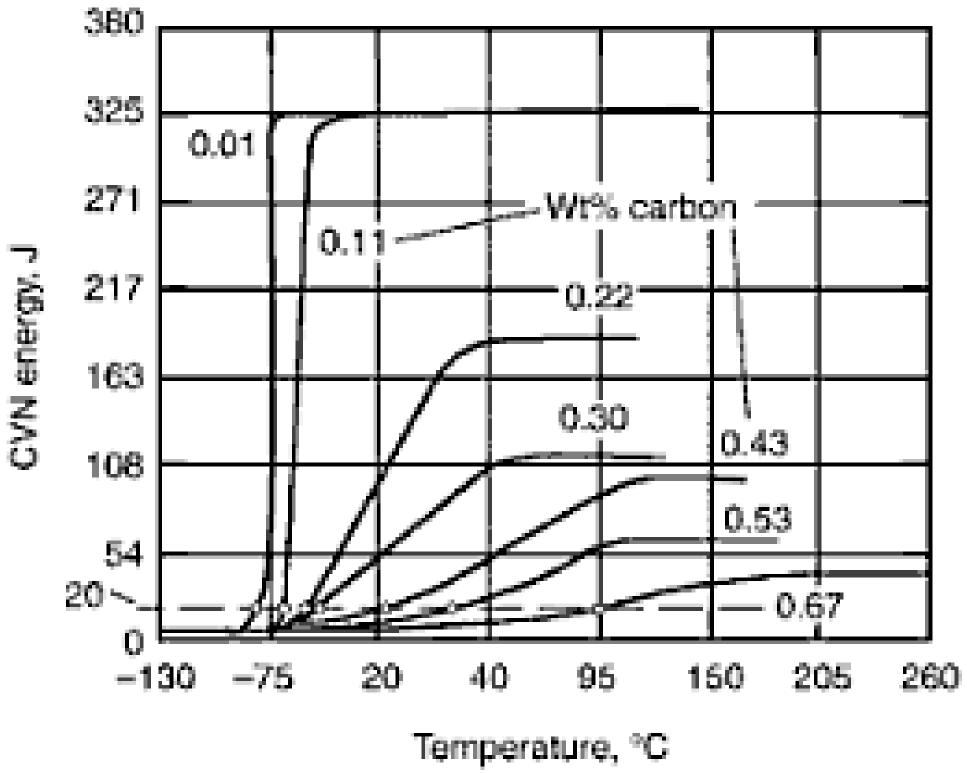


Fig. 5.9 Charpy V-notch (CVN) data on plain carbon steels austenitized at 870°C (1600°F) for 4 h and slow cooled. Source: Ref 5.3

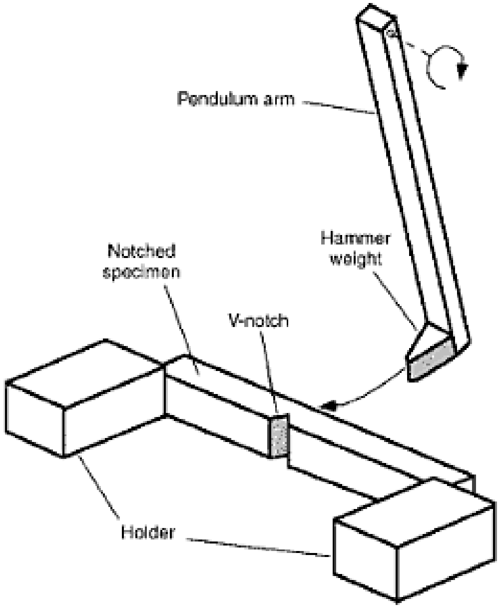
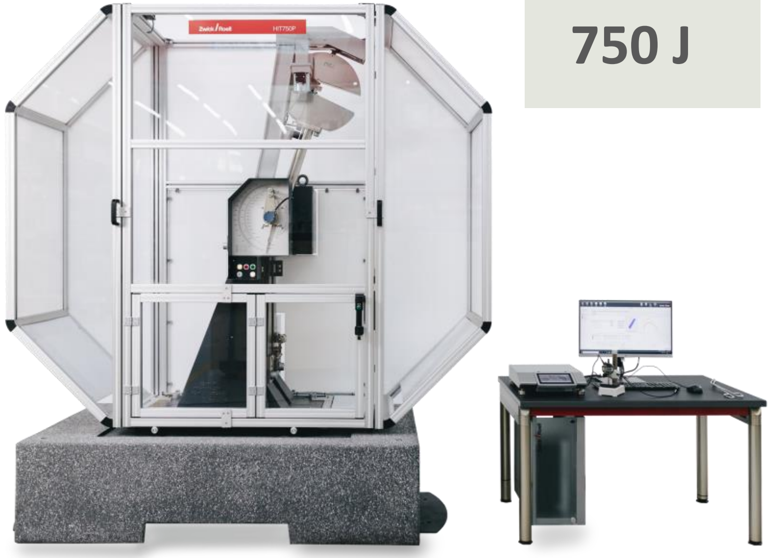
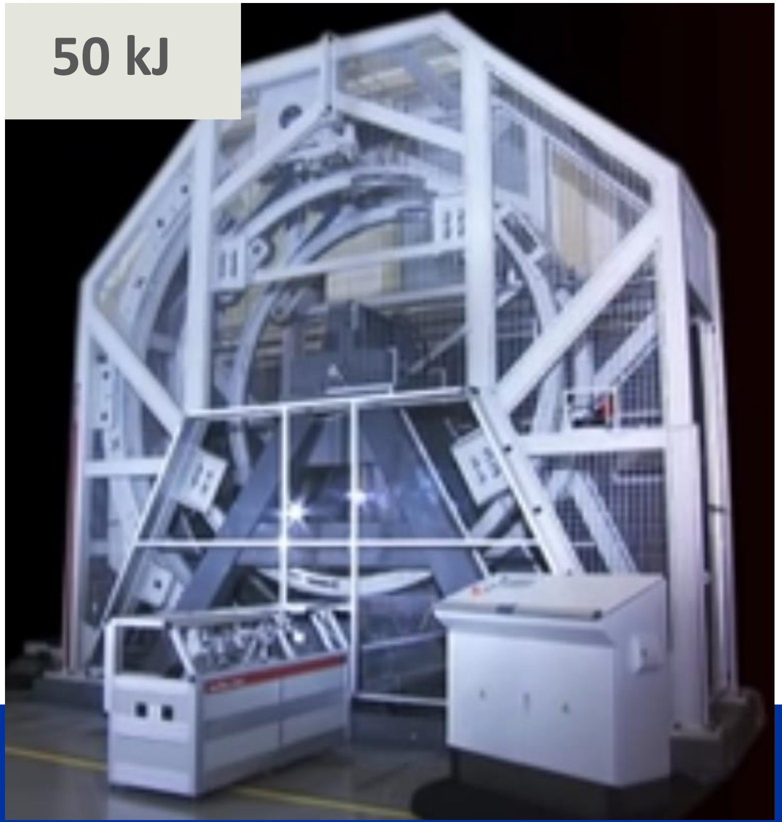


Fig. 5.8 Schematic diagram of the Charpy impact test

Source, ASM Handbook



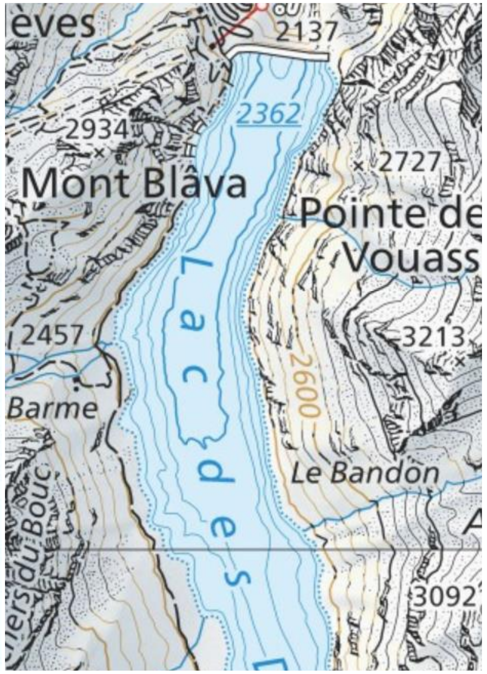
750 J

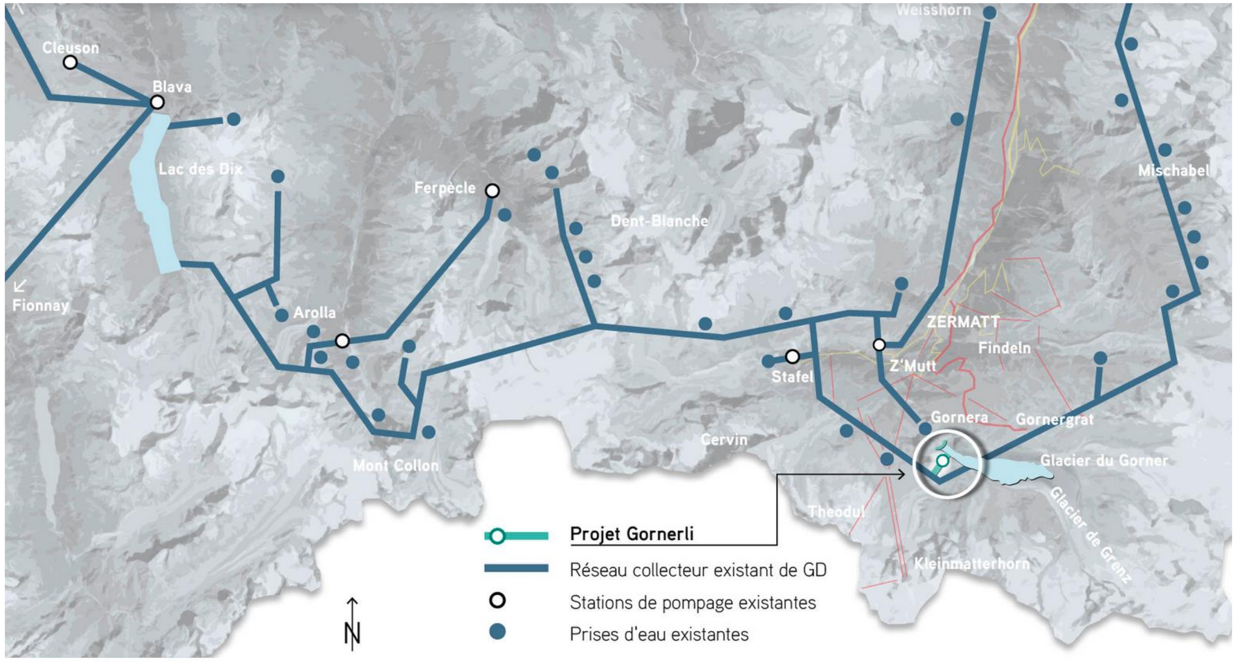


50 kJ

Courtesy of Zwick Roell

4. Case study: hydrogen embrittlement





The Grande Dixence Dam is the tallest gravity dam in the world. It is part of the Cleuson-Dixence Complex. The dam fuels four power stations, totaling the installed capacity to 2,069 MW. This enables the output of two large nuclear power plant to be fed into the high voltage grid in just three minutes

“On **December 12, 2000**, the three groups at the Bieudron plant were **put into service around 7 a.m.** and **operated normally throughout the day**. The order to stop them (stopping production) was given between 8:02 p.m. and 8:03 p.m. by the EOS control post in Lausanne, in accordance with customary practices in this area. From 8:06 p.m., there was no longer any flow in the shielded well.

At 8:09 p.m., the measuring devices monitoring the development detected a sudden drop in pressure in the balance chamber and a very significant increase in flow rate in the well, which caused the Tracouet head valve to automatically close, downstream of the chamber, closure which ended around 8:11 p.m.

At **the same time, an electrician foreman on standby that day received an alarm on his radio, while at the nearby Nendaz factory, and then saw water falling from the mountain**, which led him to alert his superiors. He then joined the hydraulic room of the Bieudron factory, where he **manually closed the head valve of the Grande Dixence dam in order to secure the installation**.

Between 8:09 p.m. and 8:14 p.m., part of the water found in the balance chamber as well as that found in the section of the armored well between Tracouet and a point located some 350 meters downstream from the Perua window , at an altitude of 1234 meters, **emerged on the surface, the well being, at this location, buried at a depth of approximately 60 meters.** According to estimates, **between 25,000 and 40,000 m3 of water gushed into the open air, after rushing into a 9 meter long tear.**”

4. Case study: hydrogen embrittlement

4. Case study: hydrogen embrittlement

« (…) a hardened steel with a high elastic limit (HLE), in particular type **S 890 QL”** was used “to create such a well.” Prior studies “showed that the **weldability of the S 890 QL steel was very satisfactory** and that submerged arc welding (AS) presented a slight superiority over the other welding processes evaluated and likely to be used, namely manual welding with

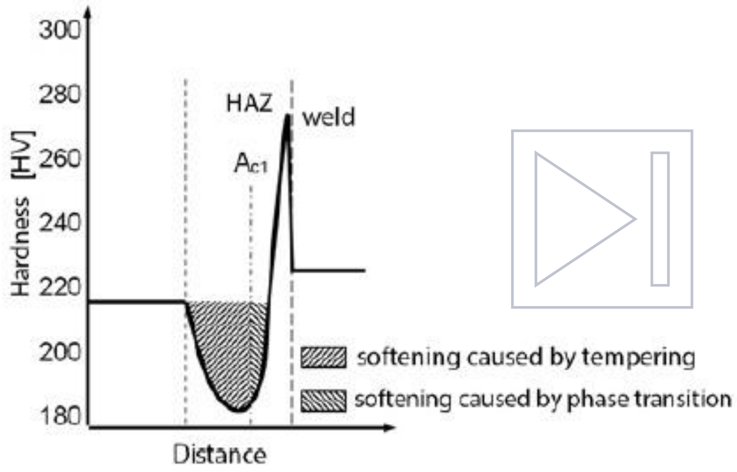


Fig. 12. Hardness distribution HV in welded joint made of toughened steel of Re>500MPa (QT), $t_{8/5}$=30s [13]

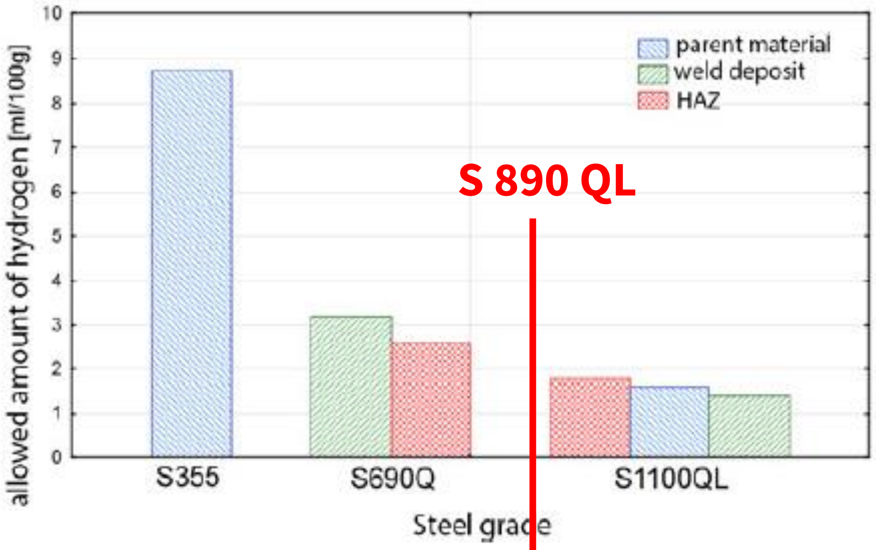


Fig. 10. Allowed hydrogen content in parent metal depending on steel grade (yield point) [44]

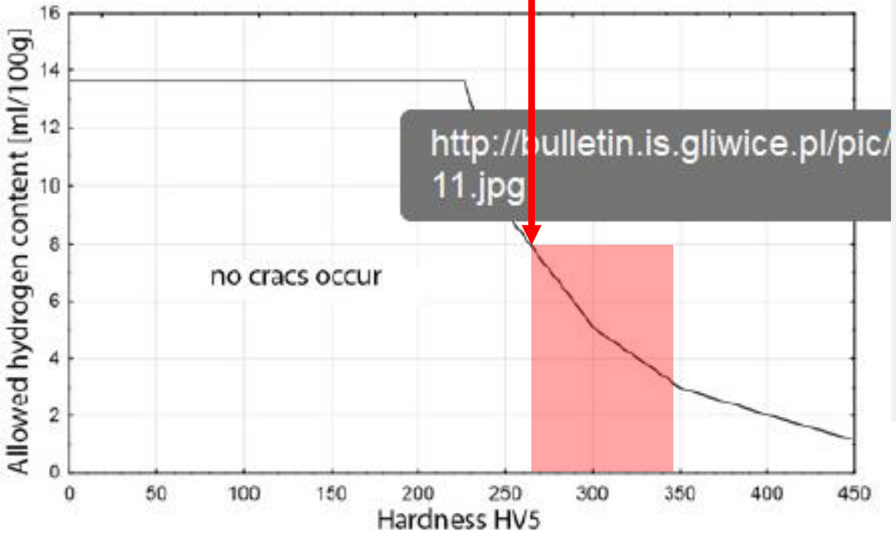
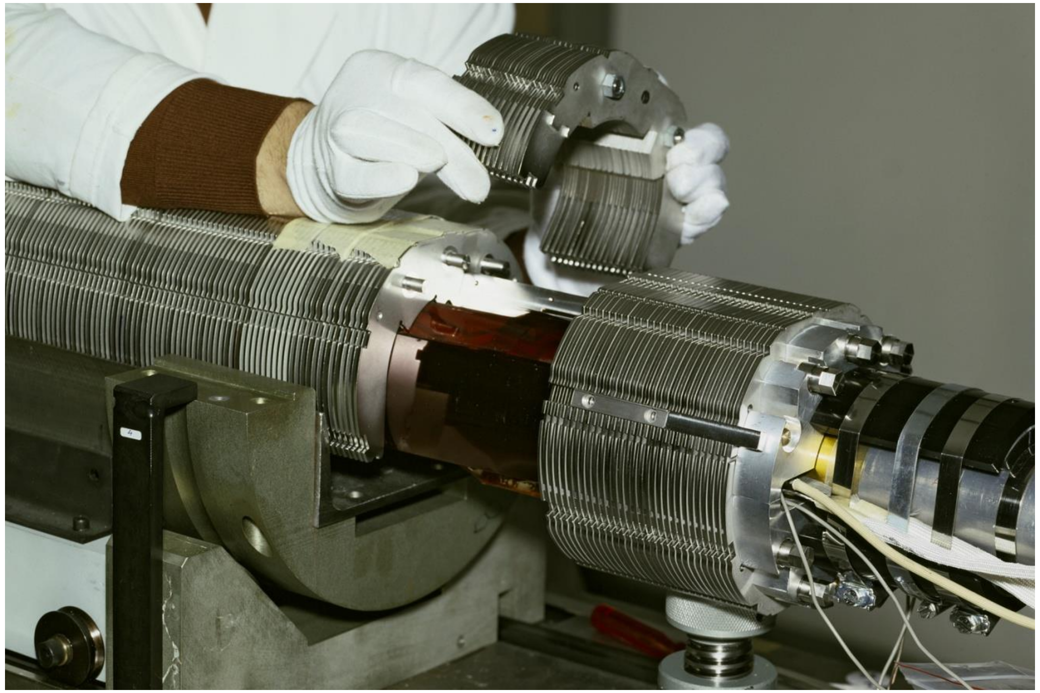


Fig. 11. Allowed hydrogen content in weld deposit depending on the grade of filler metal (weld deposit hardness) [46]

“In December 2000 there was a catastrophic collapse of the steel lined shaft at the Cleuson Dixence Scheme in Switzerland. This pipe was fabricated by using **high strength steel grade S 890 Q** which had **never been done before**. Comprehensive investigations about this failed case revealed that the collapse was caused by the **presence of large cracks in the welds**. These cracks had appeared due to the fact that the welding and testing procedures they applied **did not take into consideration the much higher sensitivity of high strength steel grades against crack formation during the welding process**.”

⇑ From: High Strength Steels for hydropower plants, Design & Concepts – Pressure Conduits, 18-20/09/2013, Graz, Austria, Proc. 3rd Int. Conference

4. Case study: collaring press



S Izquierdo Bermudez *et al*

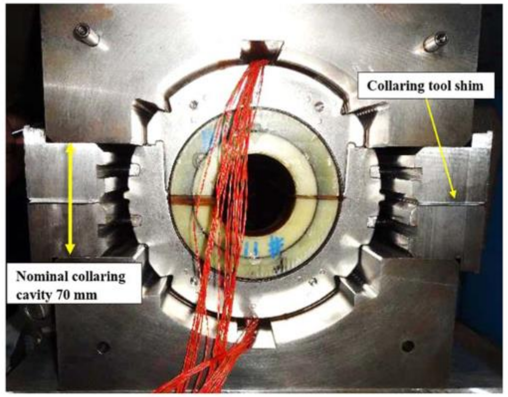
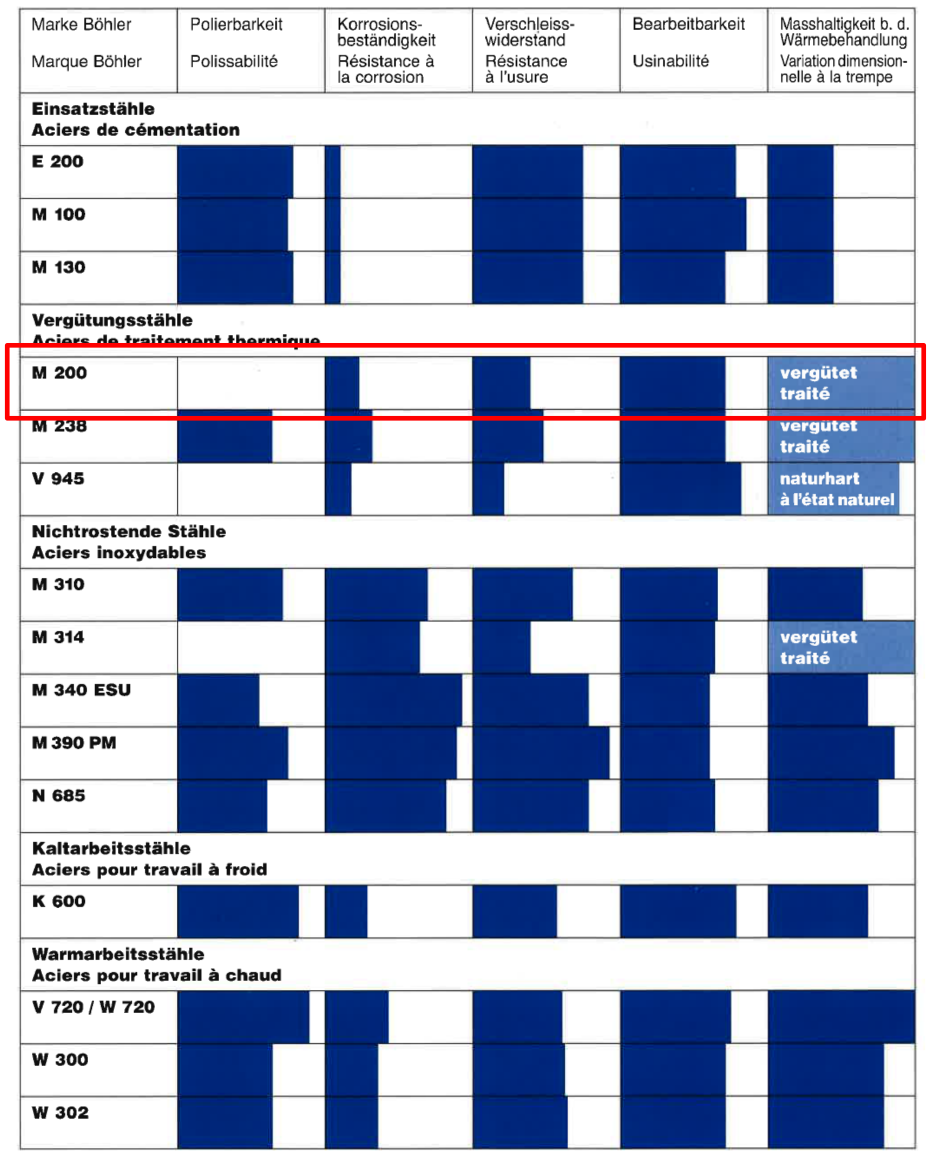


Figure 10. Illustration of the collared coil assembly without compression, with an interference of the key slots of 0.15 mm and the assembly under compression at which the key slots are aligned.

S Izquierdo Bermudez et al 2019 Supercond. Sci. Technol. 32 085012

Eigenschaftsmerkmale von Kunststoff-Formenstählen

Propriétés des aciers pour moules

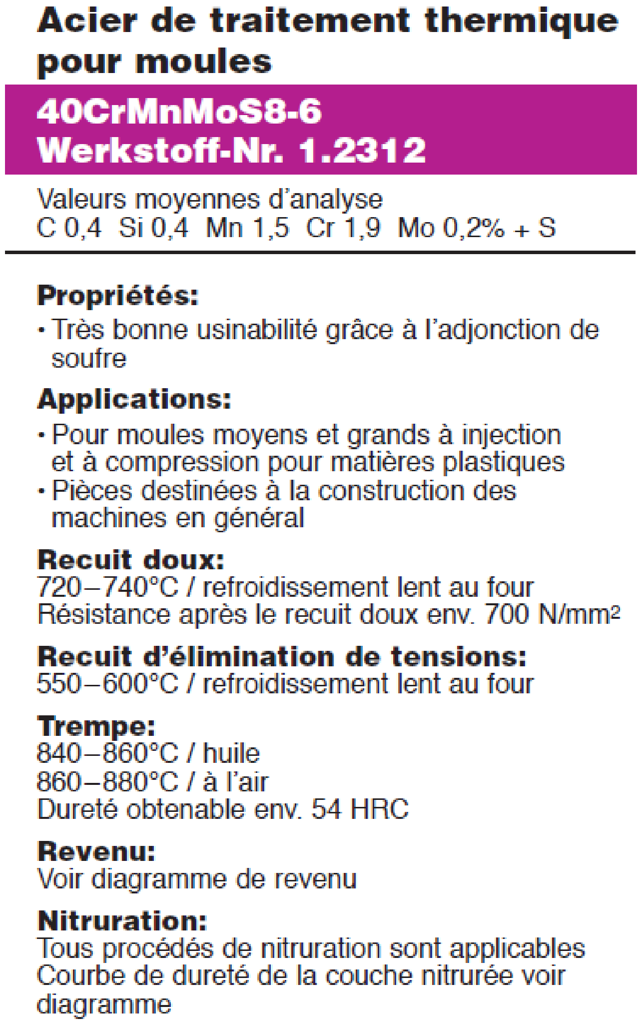


Marke Böhler Marque Böhler	Polierbarkeit Polissabilité	Korrosions-beständigkeit Résistance à la corrosion	Verschleiss-widerstand Résistance à l'usure	Bearbeitbarkeit Usinabilité	Masshaltigkeit b. d. Wärmebehandlung Variation dimensionnelle à la trempe
Einsatzstähle Aciers de cémentation					
E 200					
M 100					
M 130					
Vergütungsstähle Aciers de traitement thermique					
M 200					**vergütet traité**
M 238					**vergütet traité**
V 945					**naturhart à l'état naturel**
Nichtrostende Stähle Aciers inoxydables					
M 310					
M 314					**vergütet traité**
M 340 ESU					
M 390 PM					
N 685					
Kaltarbeitsstähle Aciers pour travail à froid					
K 600					
Warmarbeitsstähle Aciers pour travail à chaud					
V 720 / W 720					
W 300					
W 302					

Source: Böhler catalogue – programme de vente 2001

4. Case study: collaring press

Source: Böhler catalogue – programme de vente 2001



Acier de traitement thermique pour moules

40CrMnMoS8-6
Werkstoff-Nr. 1.2312

Valeurs moyennes d'analyse
C 0,4 Si 0,4 Mn 1,5 Cr 1,9 Mo 0,2% + S

Propriétés:
- Très bonne usinabilité grâce à l'adjonction de soufre

Applications:
- Pour moules moyens et grands à injection et à compression pour matières plastiques
- Pièces destinées à la construction des machines en général

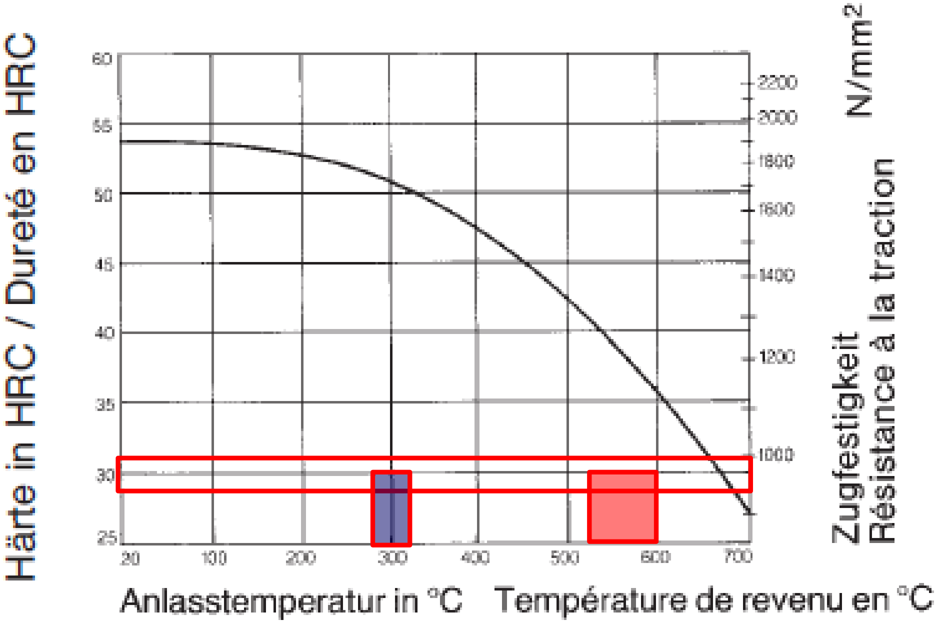
Recuit doux:
720–740°C / refroidissement lent au four
Résistance après le recuit doux env. 700 N/mm²

Recuit d'élimination de tensions:
550–600°C / refroidissement lent au four

Trempe:
840–860°C / huile
860–880°C / à l'air
Dureté obtenable env. 54 HRC

Revenu:
Voir diagramme de revenu

Nitruration:
Tous procédés de nitruration sont applicables
Courbe de dureté de la couche nitrurée voir diagramme



Supplied condition: prehardened & quenched

Process:

- ○ **Rough machining**
- ○ **Stress relieving at $T \approx T_{tempering} - 100$ °C**
- ○ **Fine machining**
- ○ **Low T heat treatment at $T \approx T_{curing} + 100$ °C**
- ○ **Finishing**
- ○ **Zn-coating (corrosion resistance, surface hardness)**

4. Case study: yield and formability

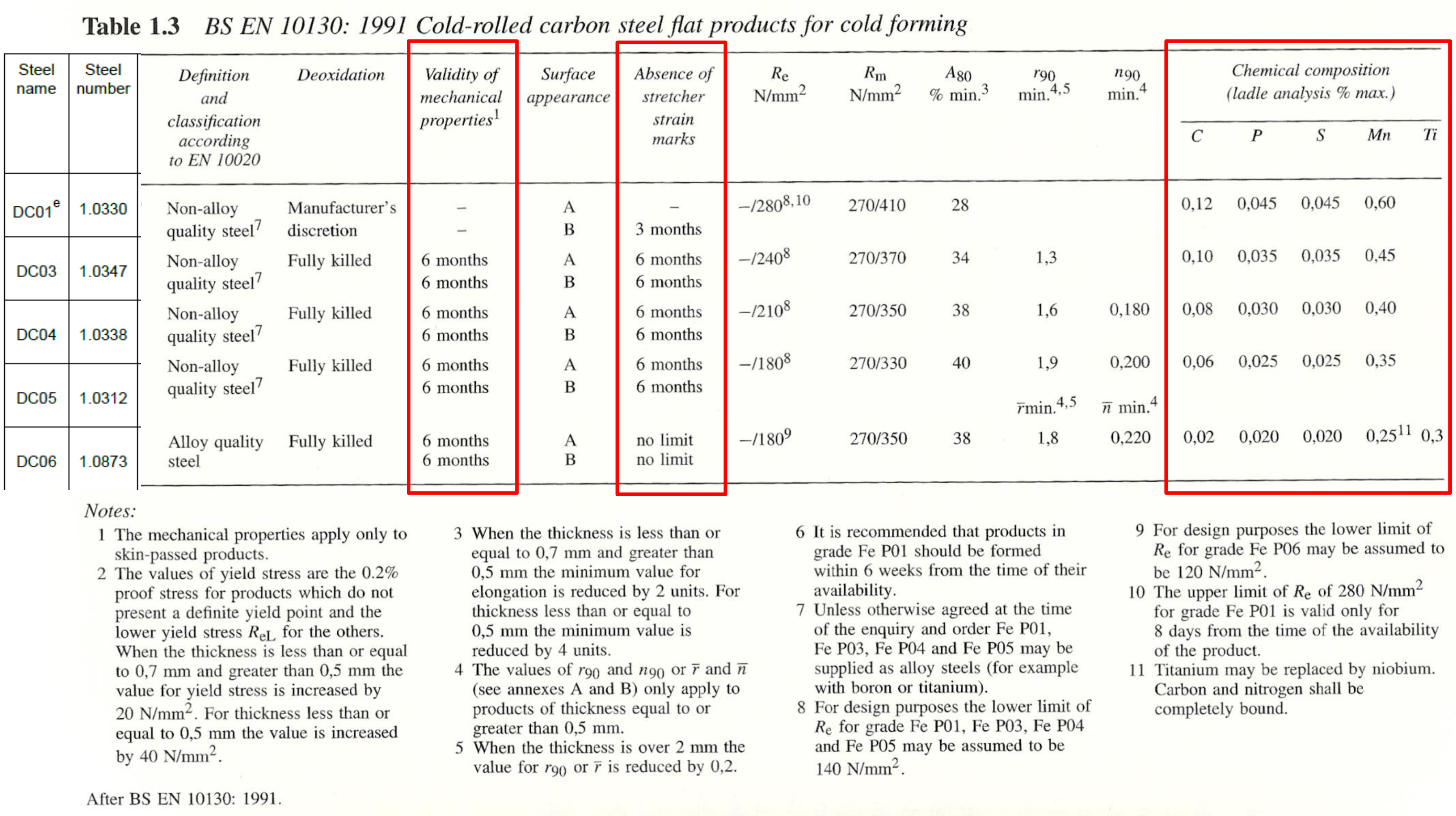


Table 1.3 *BS EN 10130: 1991 Cold-rolled carbon steel flat products for cold forming*

Steel name	Steel number	*Definition and classification according to EN 10020*	*Deoxidation*	*Validity of mechanical properties*[1]	*Surface appearance*	*Absence of stretcher strain marks*	R_e N/mm^2	R_m N/mm^2	A_{80} % min.[3]	r_{90} min.[4,5]	n_{90} min.[4]	*Chemical composition (ladle analysis % max.)* *C*	*P*	*S*	*Mn*	*Ti*
DC01[e]	1.0330	Non-alloy quality steel[7]	Manufacturer's discretion	– –	A B	– 3 months	–/280[8,10]	270/410	28			0,12	0,045	0,045	0,60	
DC03	1.0347	Non-alloy quality steel[7]	Fully killed	6 months 6 months	A B	6 months 6 months	–/240[8]	270/370	34	1,3		0,10	0,035	0,035	0,45	
DC04	1.0338	Non-alloy quality steel[7]	Fully killed	6 months 6 months	A B	6 months 6 months	–/210[8]	270/350	38	1,6	0,180	0,08	0,030	0,030	0,40	
DC05	1.0312	Non-alloy quality steel[7]	Fully killed	6 months 6 months	A B	6 months 6 months	–/180[8]	270/330	40	1,9	0,200	0,06	0,025	0,025	0,35	
										$\bar{r}$min.[4,5]	$\bar{n}$ min.[4]					
DC06	1.0873	Alloy quality steel	Fully killed	6 months 6 months	A B	no limit no limit	–/180[9]	270/350	38	1,8	0,220	0,02	0,020	0,020	0,25[11]	0,3

Notes:

1 The mechanical properties apply only to skin-passed products.

2 The values of yield stress are the 0.2% proof stress for products which do not present a definite yield point and the lower yield stress R_{eL} for the others. When the thickness is less than or equal to 0,7 mm and greater than 0,5 mm the value for yield stress is increased by 20 N/mm^2. For thickness less than or equal to 0,5 mm the value is increased by 40 N/mm^2.

3 When the thickness is less than or equal to 0,7 mm and greater than 0,5 mm the minimum value for elongation is reduced by 2 units. For thickness less than or equal to 0,5 mm the minimum value is reduced by 4 units.

4 The values of r_{90} and n_{90} or $\bar{r}$ and $\bar{n}$ (see annexes A and B) only apply to products of thickness equal to or greater than 0,5 mm.

5 When the thickness is over 2 mm the value for r_{90} or $\bar{r}$ is reduced by 0,2.

6 It is recommended that products in grade Fe P01 should be formed within 6 weeks from the time of their availability.

7 Unless otherwise agreed at the time of the enquiry and order Fe P01, Fe P03, Fe P04 and Fe P05 may be supplied as alloy steels (for example with boron or titanium).

8 For design purposes the lower limit of R_e for grade Fe P01, Fe P03, Fe P04 and Fe P05 may be assumed to be 140 N/mm^2.

9 For design purposes the lower limit of R_e for grade Fe P06 may be assumed to be 120 N/mm^2.

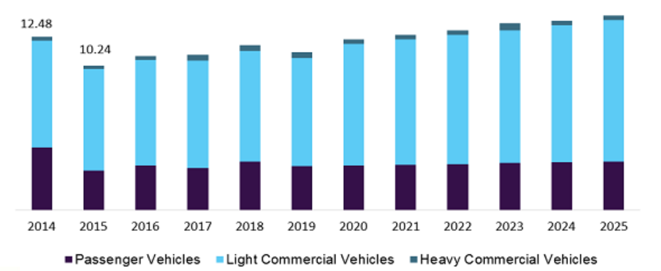
10 The upper limit of R_e of 280 N/mm^2 for grade Fe P01 is valid only for 8 days from the time of the availability of the product.

11 Titanium may be replaced by niobium. Carbon and nitrogen shall be completely bound.

After BS EN 10130: 1991.

Courtesy of Thyssenkrupp AG

U.S. automotive steel market size, by vehicle type, 2014 - 2025 (USD Billion)

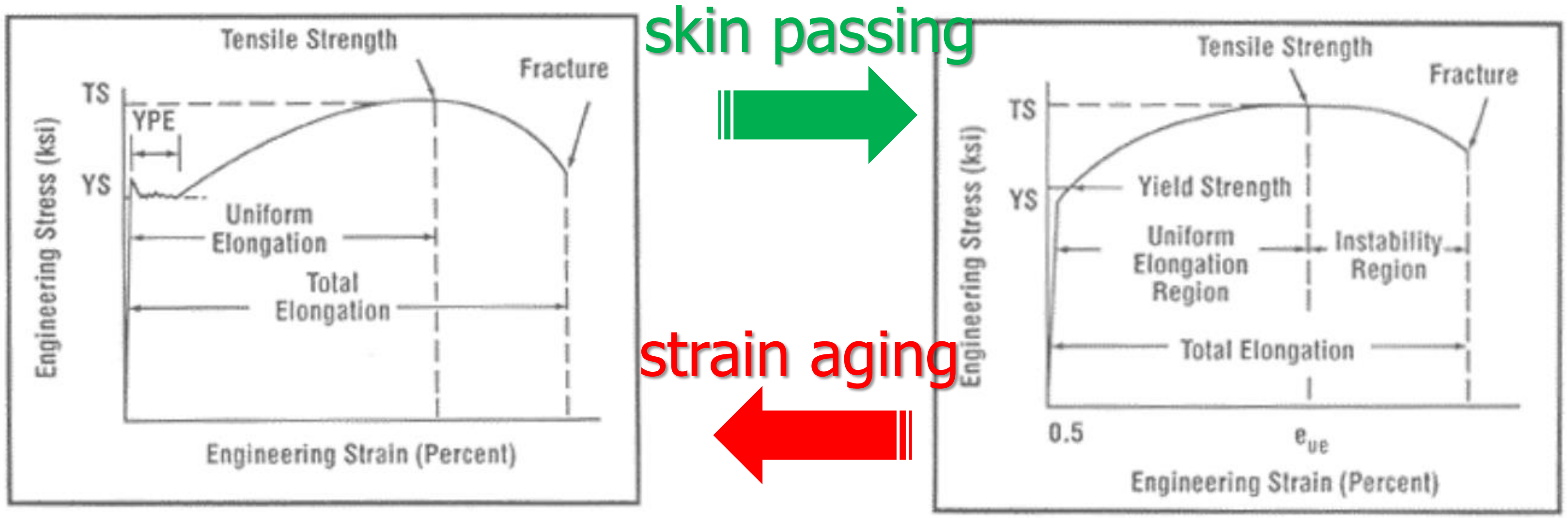


Typically "Ultra Low Carbon (ULC) Interstitial Free Steels"

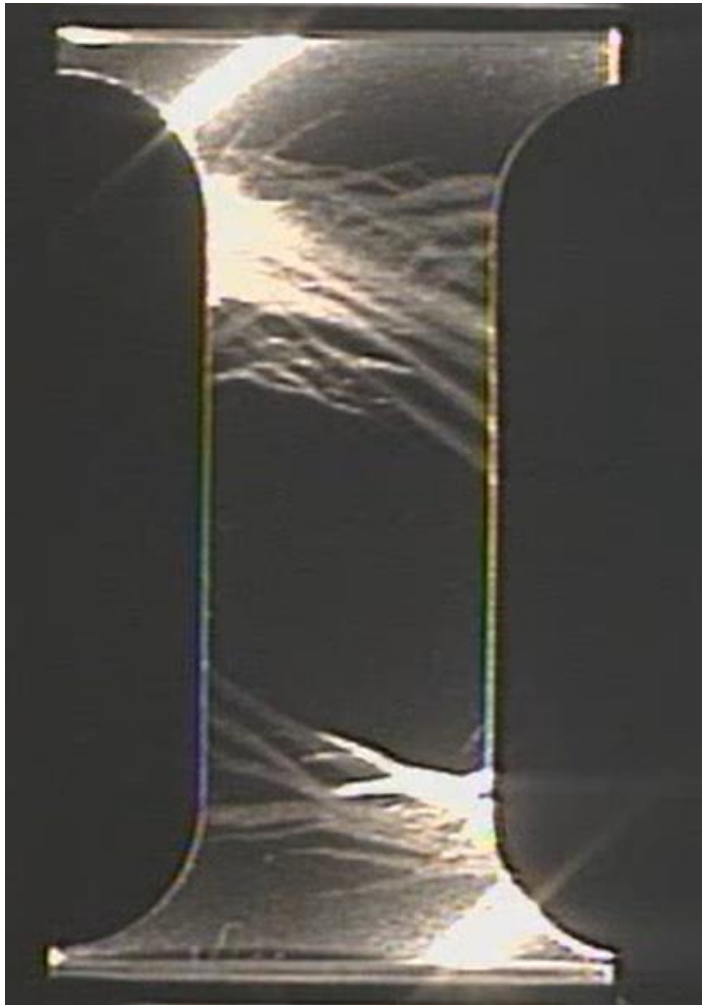
4. Case study: yield and formability

Strain Aging: “A phenomenon that occurs in some materials following plastic deformation. In low-carbon steel sheet, strain aging results in a return of discontinuous yielding, an increase in yield strength and hardness, and a decrease in ductility without a substantial change in tensile strength.”

If the steel is not pressed within a specified time after skin passing, removing the yield point, strain aging will result in the return of the yield point



Stress-strain curve with yield point phenomenon - (Source: Auto/Steel Partnership)



Source: M. Meyer, Lüders Bands in Steel

http://vimeo.com/4586024

Also AlMg alloys et al.: see ⇒ I. Aviles, Non Ferrous Materials, later today

5. Conclusions

1. Ferrous alloys - a complex family of materials
2. Understanding properties:
   - Influence of alloying elements
   - Effect of heat treatments
3. Several equilibrium and non-equilibrium phases
   - predictable from the phase diagram (α, γ, Fe_3C…)
   - or due to diffusionless transformation (martensite)
   - susceptible to be shaped by HT
4. The Fe-Fe_3C diagram basis for the understanding of the metallurgy of ferrous materials
   - Properties mainly conferred by HT
   - Properties predictable and tailored on the basis of steelmaker information, or specific dedicated tests (Jominy)
5. Martensitic transformation are at the basis of treatment of "heat treatable" steels