Department of Materials Science and Engineering

Classification of steels

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Materials Engineering
BMEGEMTBGF1
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Classification according to

1) Steel production methods (old category)
2) Structure at room temperature
3) Content of alloying elements
4) Purpose of utilization

Content of alloying elements

Plain (carbon) steels

Because of the steel making process contains unavoidable elements

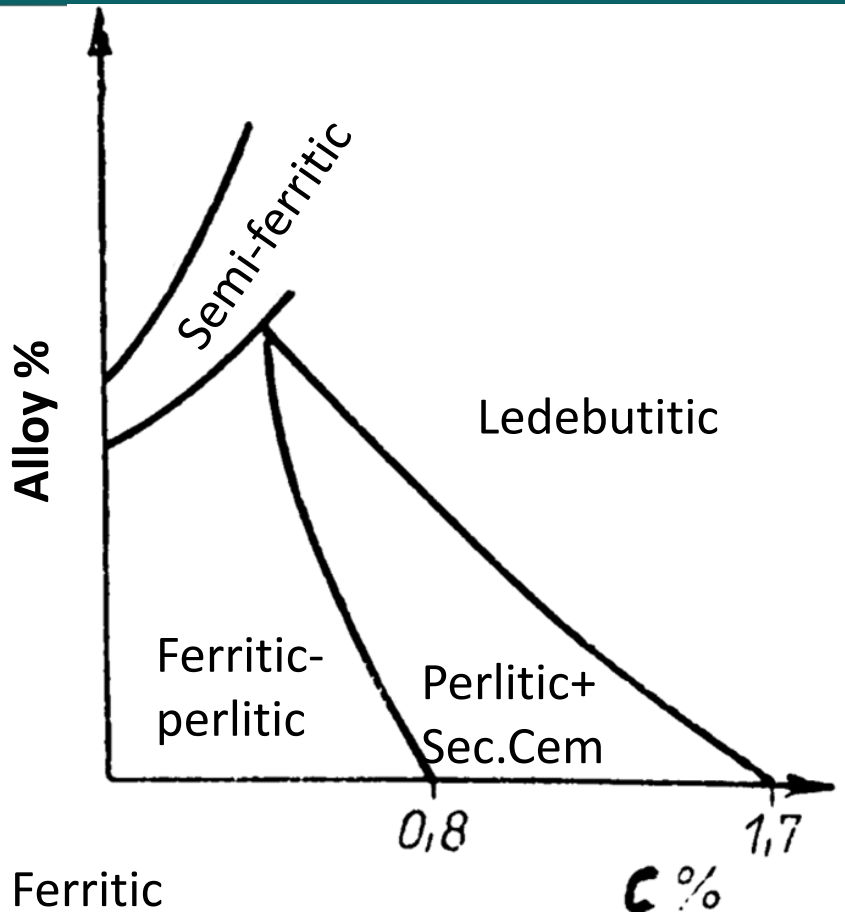
Mn < 0.8 % Si < 0.6 % Cr, Ni, Cu <0.3 %

Mo, W < 0.2 % Al, Ti, V, Nb < 0.05 %

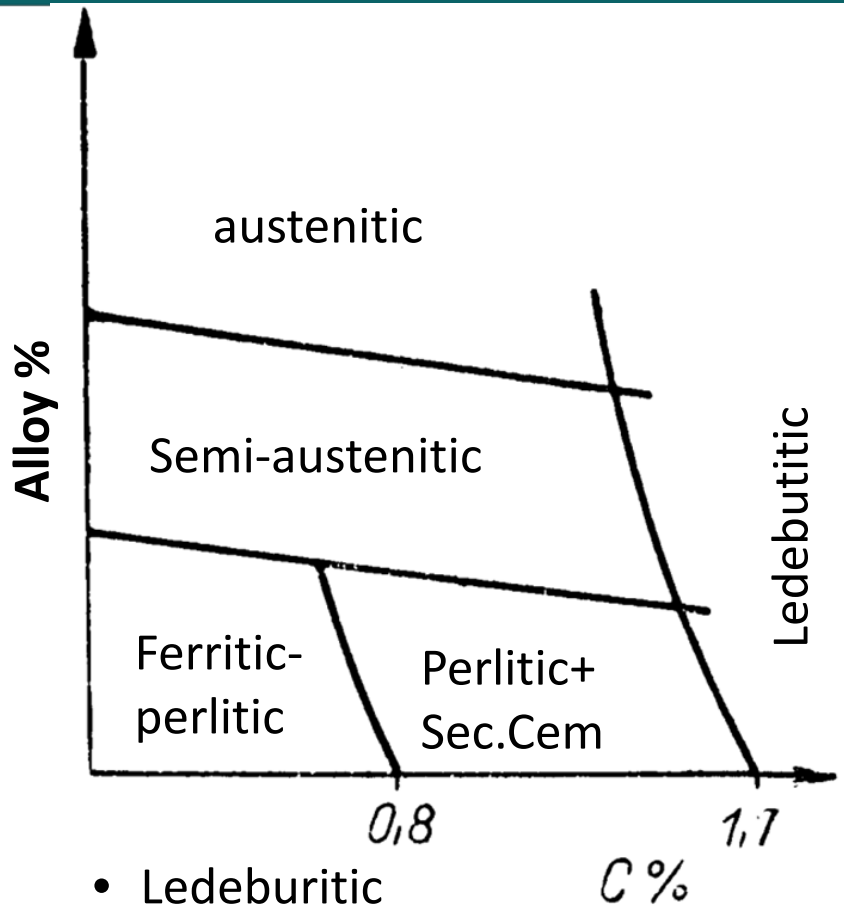
Alloyed steels

- micro alloyed steels Σ alloy < 0.1% (Ti, Ni, V, …)
- low alloyed steels Σ alloy < 5 %
- medium alloyed steels Σ alloy < 10 %
- high alloyed steels Σ alloy > 10 %

Structure at room temperature

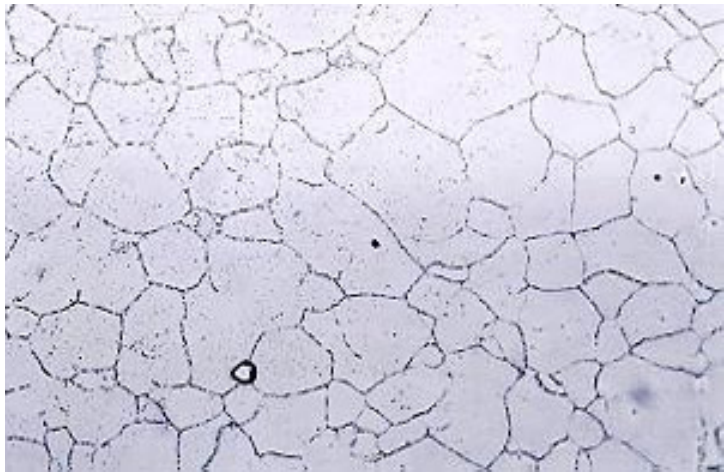


- Ferritic
  - Ferrite promoting element
- Semi ferritic
- Hipoeutektoidic
- Hipereutektoidic

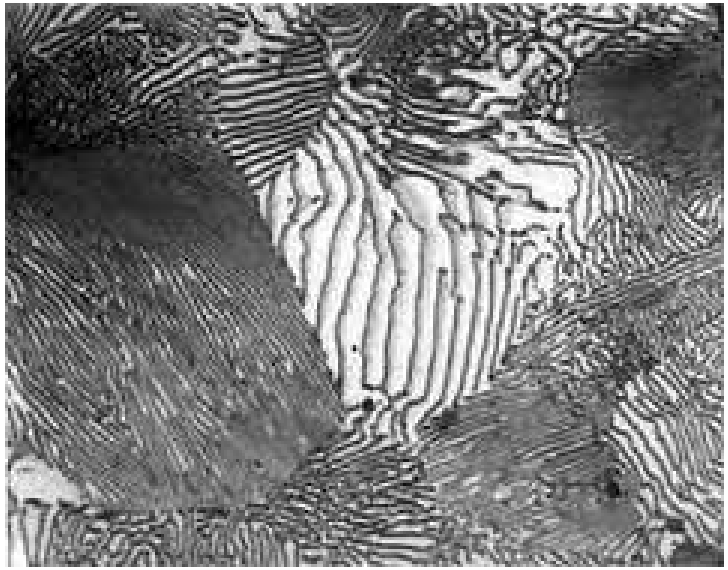


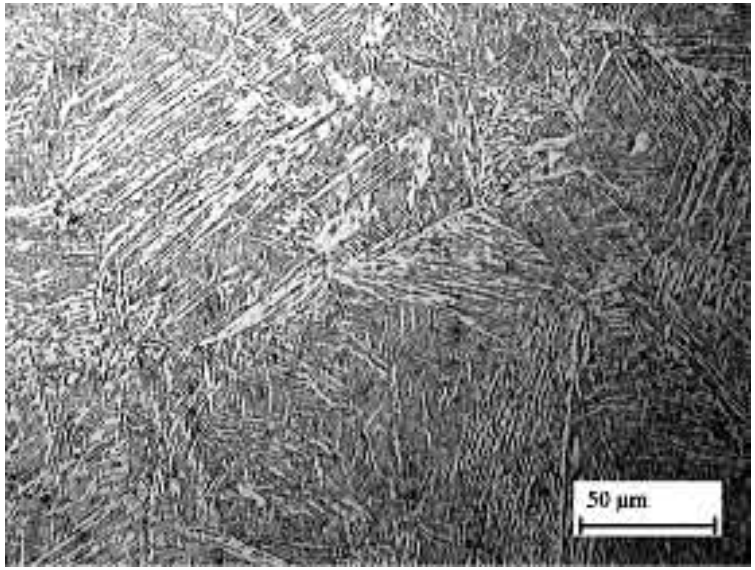
- Ledeburitic
- Semi austenitic
- Austenitic
  - Austenite promoting element

Structure at room temperature



- Perlitic
- Martensitic
- Austenitic
- Ferritic
- Bainitic





Utilization

- Structural steels
  - Automotive industry, machine industry , steel structures
  - Toughness is also a requirement
  - C < 0,6%
- Tool steels
  - Machining and forming tools
  - Wear resistance, stiffness, hardness
  - Hardenable, precipitation hardenable alloys
- Special steels and alloys
  - For a specific purpose
    - Heat resistance, corrosion resistance, etc.

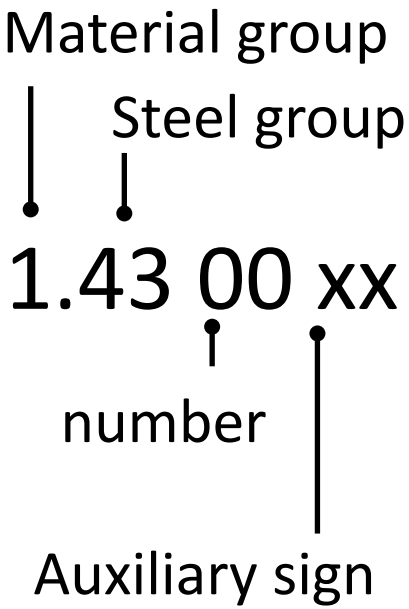
Designation of steels

According to different standards

Most well-known standards:

- International Standard Organization **ISO**
- American Iron and Steel Institute **AISI**
- Society of Automotive Engineer **SAE**
- American Society for Testing and Materials **ASTM**

Example: number (werkstoffnummer)



1 – steels

2 – heavy metals

3 – light metals

4 – nonmetallic

…

8 – nonmetallic

9 – rest

Short designation

sign	Application Area	Main prop.	e.g.
S	Structural steel	R_{eH} (MPa)	S235
P	Pressure vessel steel	R_{eH} (MPa)	P275
L	Pipe steels	R_{eH} (MPa)	
E	Steels for machines	R_{eH} (MPa)	E235
B	Steels for concrete	R_{eH} (MPa)	
…	…	…	…

Auxiliary signs

Auxiliary signs			Temperature (°C)
Required impact energy			
27 J	40 J	60 J	
JR	KR	LR	+20
J0	K0	L0	0
J2	K2	L2	-20
J3	K3	L3	-30
J4	K4	L4	-40
J5	K5	L5	-50
J6	K6	L6	-60

Designation according to chemical composition

Carbon steels: C10, C40, C90, C120

Alloyed steels:

14NiCrMo13-4

high alloy steels:

X8CrNiTi18-10

Alloying element	Multiplication factor
Cr, Co, Mn, Ni, Si, W	4
Al, Be, Cu, Mo, Nb, Pb, Ta, Ti, V, Zr	10
C, Ce, N, P, S	100
B	1000

Structural steels

A: hot rolled structural steels

B: flat steel products for pressure vessels

Formability, weldability

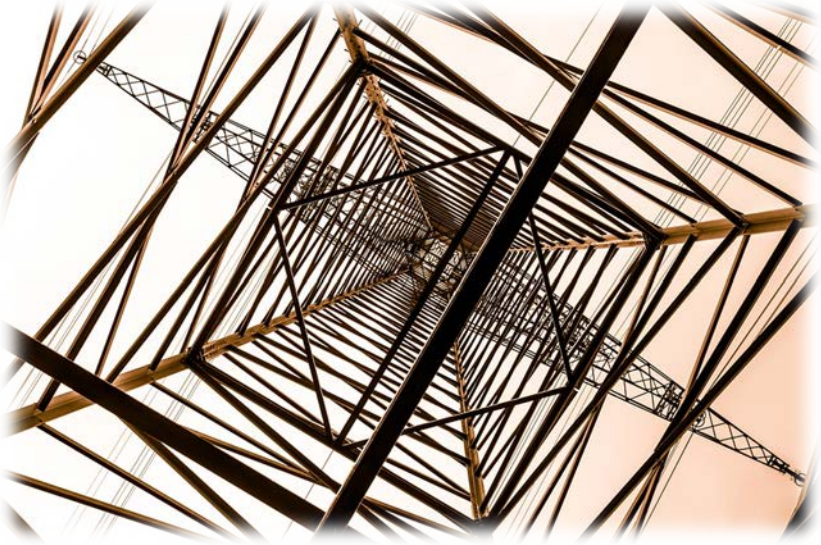
C: Steels for cold forming

D: Heat treatable steels

E: Case hardening steels

F: Nitridable steels

Other types of steels



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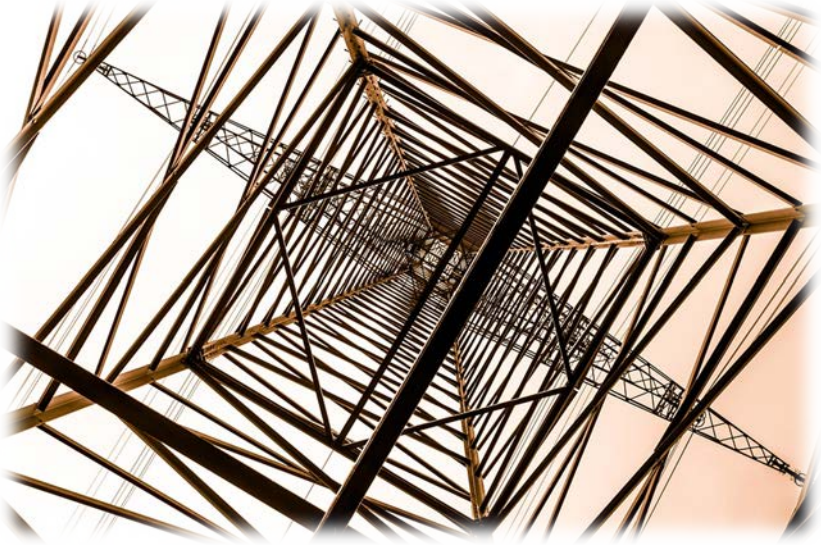

A: Hot rolled unalloyed structural steels

- For general purpose
- Hot rolled of forged state
- Certificate: R_m, R_{eH}, A, KV, chem. comp
- Can not be used in some cases
- Various types
- E.g.: S235JR

A: Normalized rolled, weldable, fine-grained steels

- Normalized during rolling
- Grain size number greater than 6
- Auxiliary mark:
  - N: normalized
  - L: impact energy 27 J at -50°C
- E.g.: S275N, S275NL

A: Thermomechanical rolled, weldable, fine-grained steels

- Thermomechanical rolling: controlled recrystallization during deformation
- Nb alloying increases the recrystallization temperature
- The grain refinement is promoted by Ti-alloying
- Auxiliary mark: M
- E.g.: S355M, S355ML

A: Thermomechanical rolled, weldable, fine-grained steels II.

- Hydrogen resistant steels
- Problem: H makes the iron carbide dissociate
  - Higher temperatures speeds up the process (T>200°C)
  - Tensile stress speeds up the process

- Solution: stabile carbide producing alloying elements
  - Cr, Mo, V, W
- Better heat resistance, used in heat treated state
- Oil industry, refineries, hydrogen appliances
- HSLA steels

A: Atmospheric corrosion resistant (weathering) steels

- Atmospheric corrosion
- Cu, Cr, P, Ni, Mo alloying (low content!)
- Forming of phosphate, sulfate, hydroxide compounds – closes the pores, the corrosion stops.
- Passive layer, red-brown color, < 0.3 mm
- E.g.: S235J0W, S355J0WP

A: Sheets and bands from quenched and tempered, high strenght steels

- Welded structures for high load at low or environment temperature.
- Containers, bridges cranes etc.
- Auxiliary mark: Q
- Weldable but susceptible to cold cracking
- E.g.: S460QL

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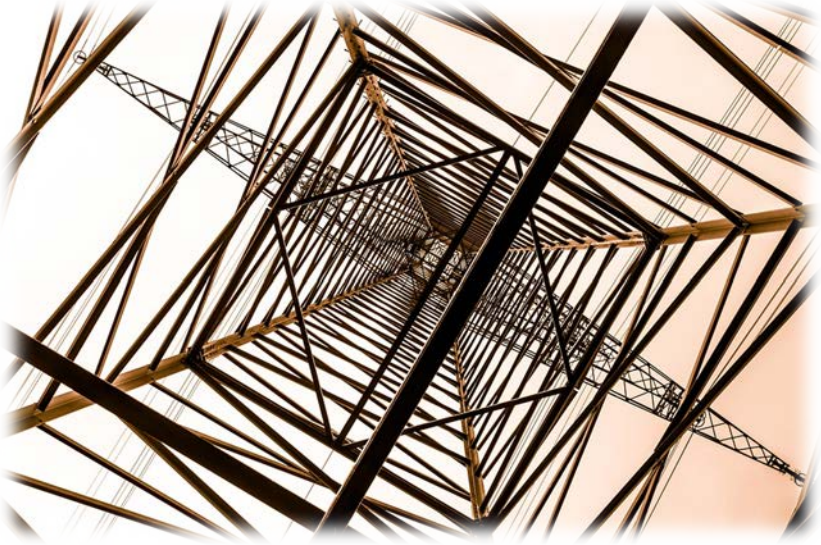
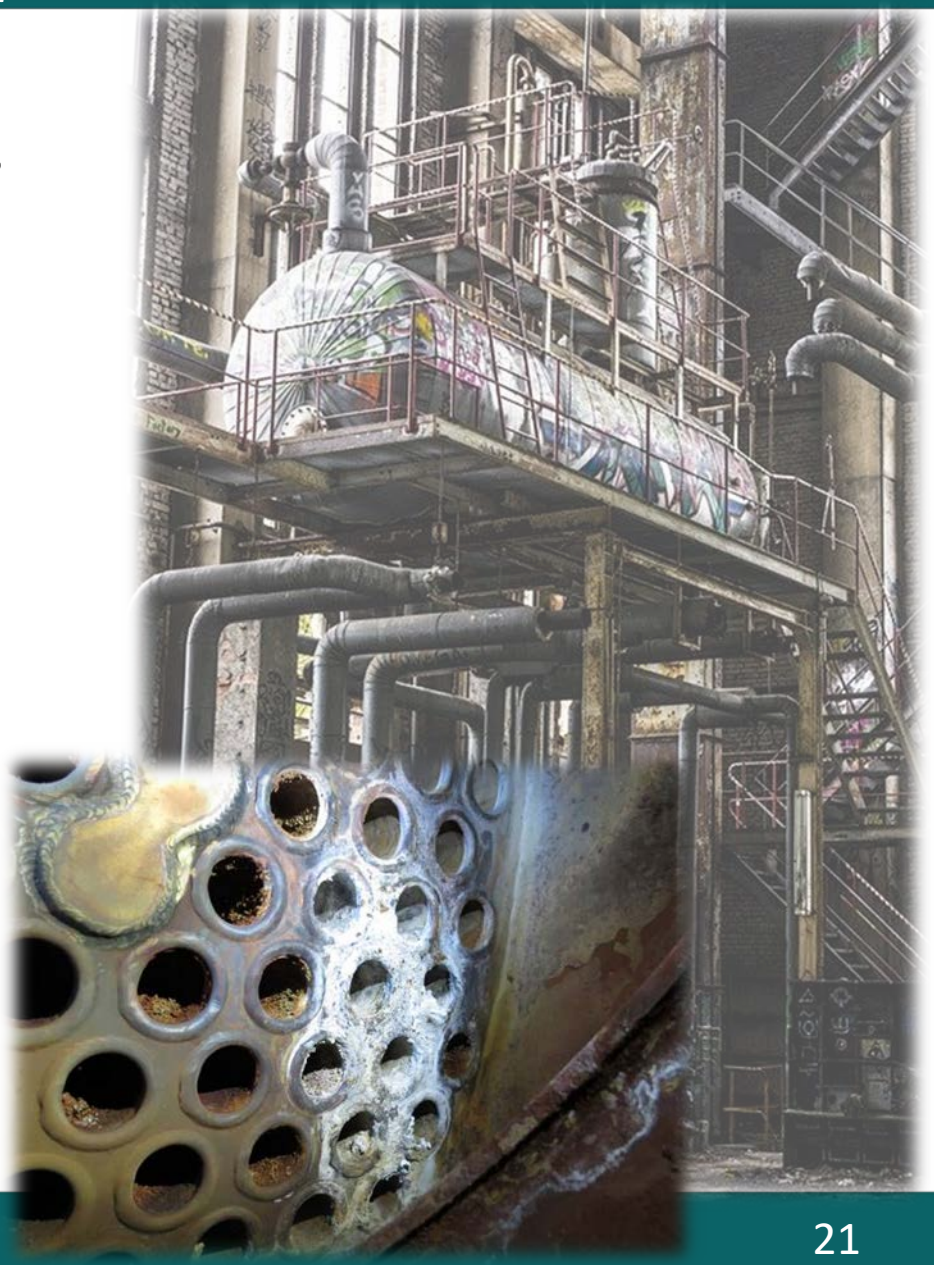


B: Plain and alloyed steels for elevated temperatures

- Plain steels (e.g.: P235GH)
  - Yield stress or creep strength is given
  - Steam boilers, pressure vessels
  - Up to ~400°C-
- Alloyed steels(e.g.: 12CrMo9-10)
  - Mn, Mo, Cr, V, Nb and Si, Ni for weldability
  - boilers, heat exchanger, chemistry appliances, flanges, fasteners
  - Up to ~500-530°C



B: Weldable fine-grained normalized steels

- Three sub-classes
- Room temperature quality (P…N)
  - T > -20°C
- Heat resistant quality (P…NH)
  - T= -20…400°C
- Sub-zero toughness (P…NL1 and P…NL2)
  - Not brittle even at T=-40 or -50°C
- Grain size number is greater than 6
- Welding: carbon equivalent

B: Ni alloyed steels with specified low temperature properties

- The impact energy is prescribed for structures
- Below -60°C Ni alloying
- FCC lattice not sensitive to embrittlement
- Selection according to temperature and thickness
- Acceptable impact energy even at -200 °C
- Cooling and cryogen technology
- E.g.: 11MnNi5-3, 12Ni14, X7Ni9

B: Weldable fine-grained thermomechanical rolled steels

- Nb alloying to increase the recrystallizations temperature
- Ti alloying to grain refining
- V and Mo alloying to strengthen
- Auxiliary mark: M
- E.g.: P355ML1

B: Weldable, fine-grained heat treatable steels

- Three sub-classes
- Room temperature quality (P…Q)
- Heat resistant quality (P…QH)
- Sub-zero toughness quality upto -40°C (P…QNL1), down to -50°C (P…QNL2)
- Micro alloying elements for grain refining and strengthening (Ti, Nb, V, N, B)
- Weldability is influenced by: thickness, input energy, design, welding process, electrode

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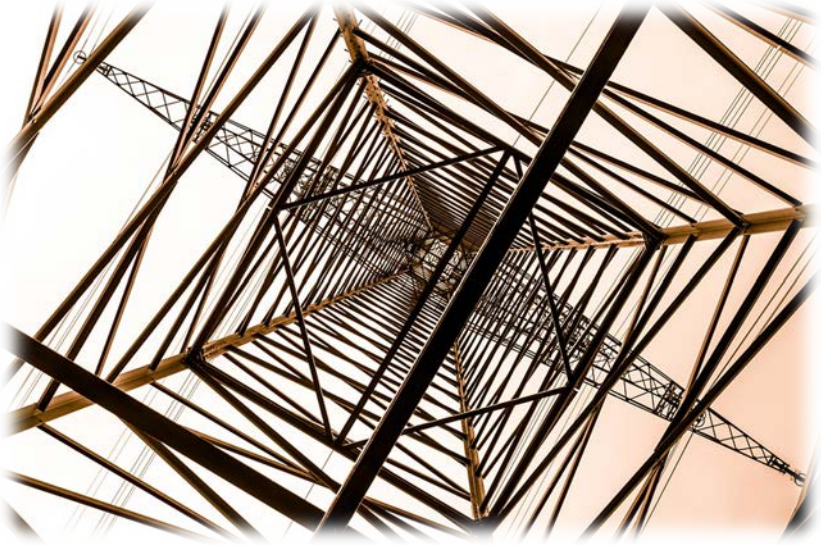


C: Cold rolled flat products from low carbon steels for cold forming

- Low carbon content, ferritic steel
- Very low alloy content (+Al, Ti)
- DC01…DC06, : A, or B – surface quality
- A: surface insufficiency (e.g. scratch) allowed
- B: no surface imperfection allowed
- Surface roughness grades
  - b: Shiny, g: semi-shiny, m: normal, r: rough
- E.g.: DC01Am

C: Cold rolled flat products from low carbon steels for cold forming

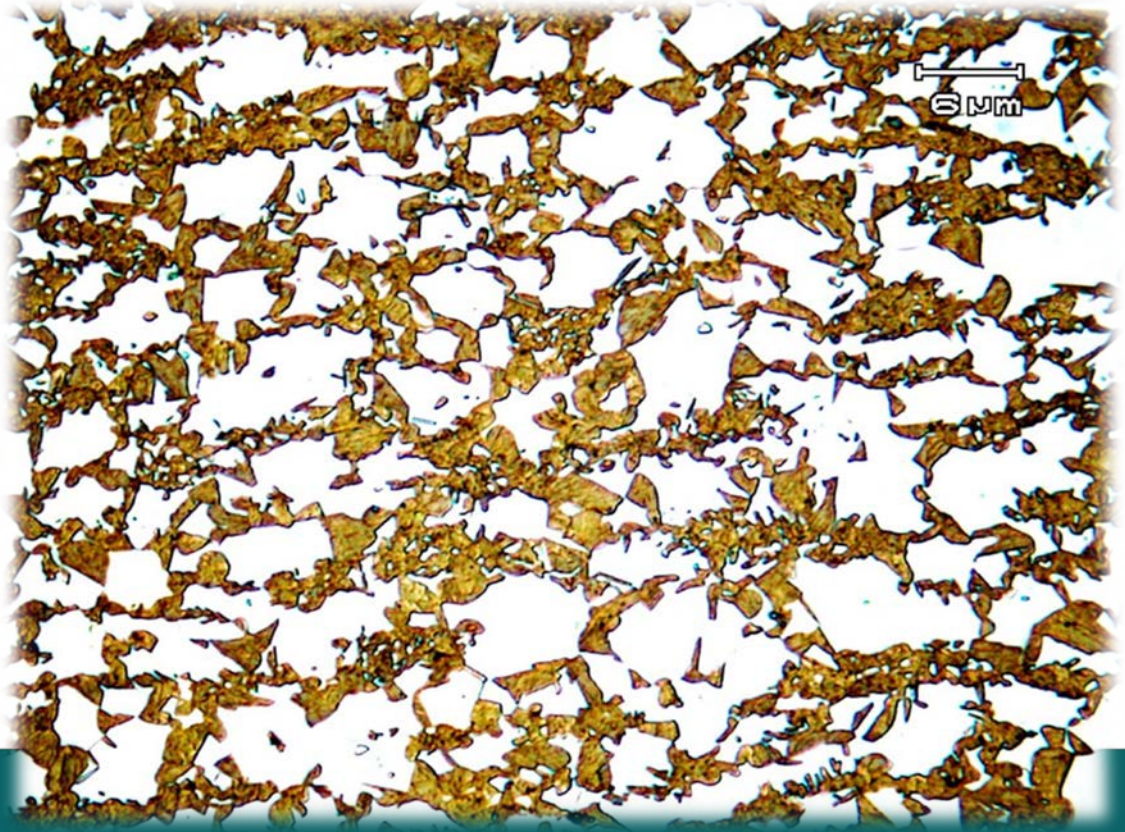
- With less than 600 mm, thickness lass than 10 mm un-alloyed and alloyed steel band
- Designation:
  - Annealed (A)
  - Cold rolled (C)
  - Skin passed (LC)
    reducing the possibility of formation of flow lines
- Surface quality MA, MB and MC
- E.g.: DC03C440MB

C: Hot rolled high strength steel flat products for cold forming

- For cold forming, hot rolled, weldable high strength, alloyed
- Thermomechanical or normalizing rolled
- Low perlite steels (Ti, Nb, V) – HSLA
- E.g.: S420NC, S460MC
- Formable, shearable, bendable, machinable
- Welded structures, automotive industry

Dual Phase steels

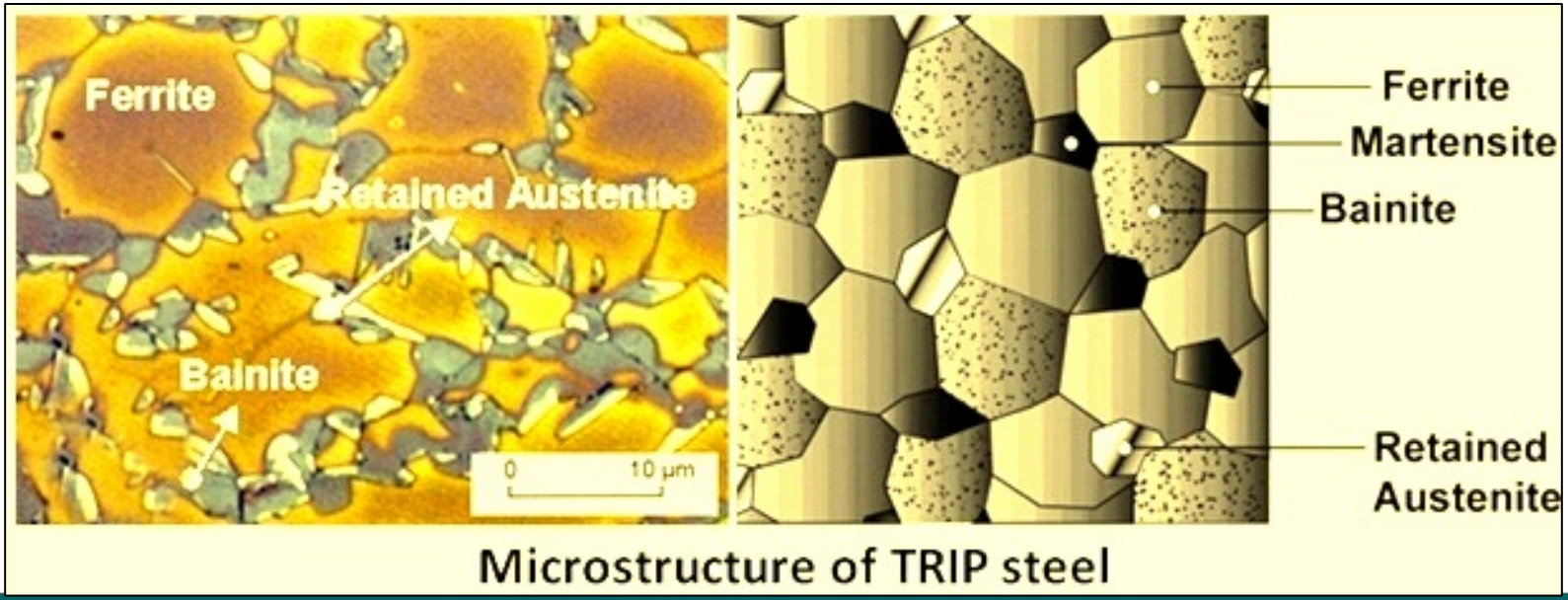
- Very hard martensite finely distributed in soft ferrite matrix
- Good strength, good formability
- Wheels, car body, bumper, wires, building structures



https://www.phase-trans.msm.cam.ac.uk/2008/dual.html

Transformation Induced Plasticity steels

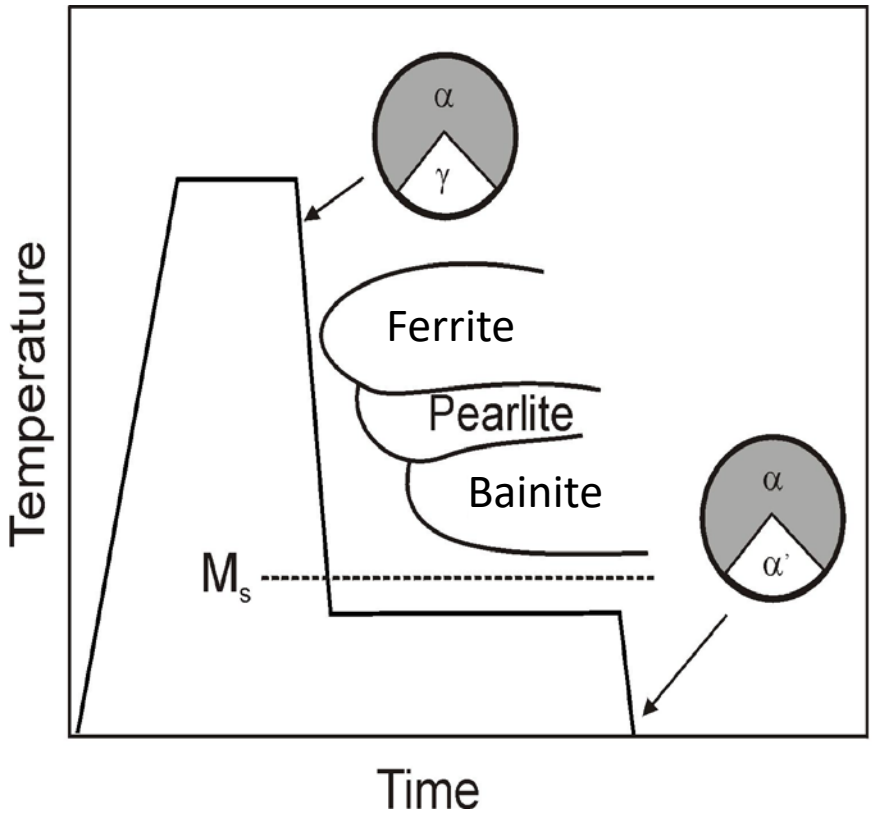
- TRIP steels
- Ferritic-austenitic-bainitic microstructure after hot forming
- Austenite transforms to martensite during further forming
- car body, vehicle industry

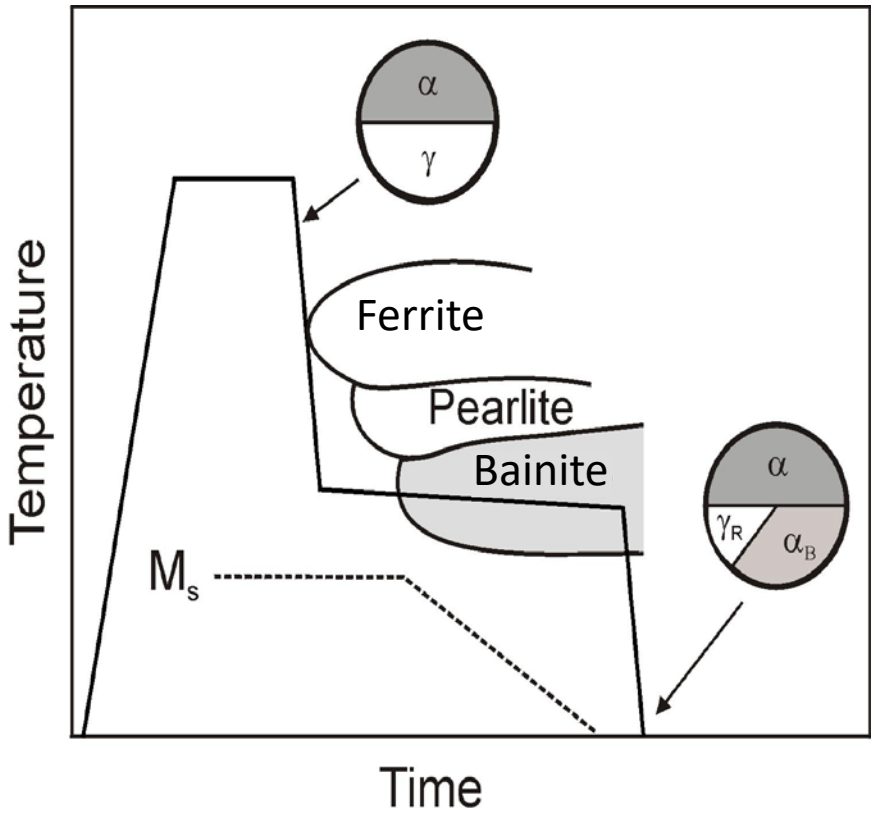


Microstructure of TRIP steel

https://www.ispatguru.com/trip-steels/

DP / TRIP treatment



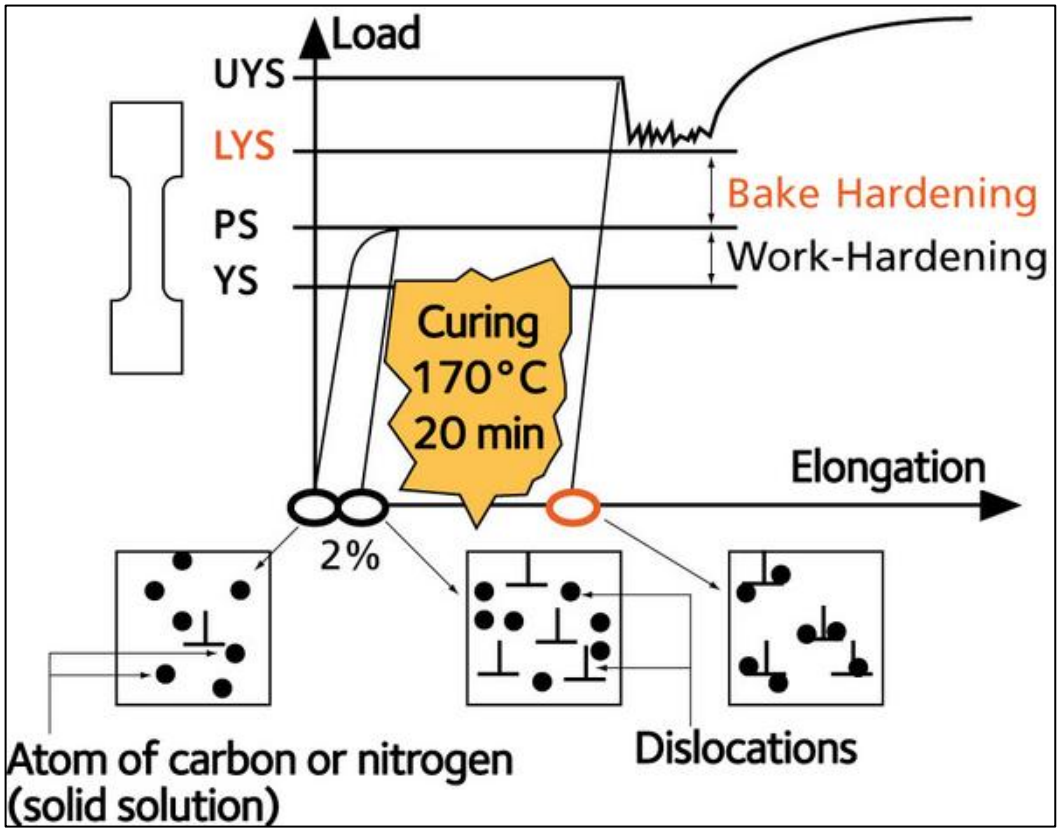


Interstitial Free steels

- IF steels
- Pure ferrite matrix
- Extra low content of alloying elements (30-60 ppm)
- Good deep drawability, formability, no ageing
- Household appliances, vehicle overlay parts

Bake Hardening steels

- BH steels
- Low carbon content alloys, precipitation hardenable at ~200°C
- Increases the yield stress by ~40 MPa though precipitation hardening (C and N)
- E.g.: after forming during painting
- Vehicle body elements



https://automotive.arcelormittal.com/products/flat/HYTSS/BH

Structural steels

A: hot rolled structural steels

B: flat steel products for pressure vessels

Formability, weldability

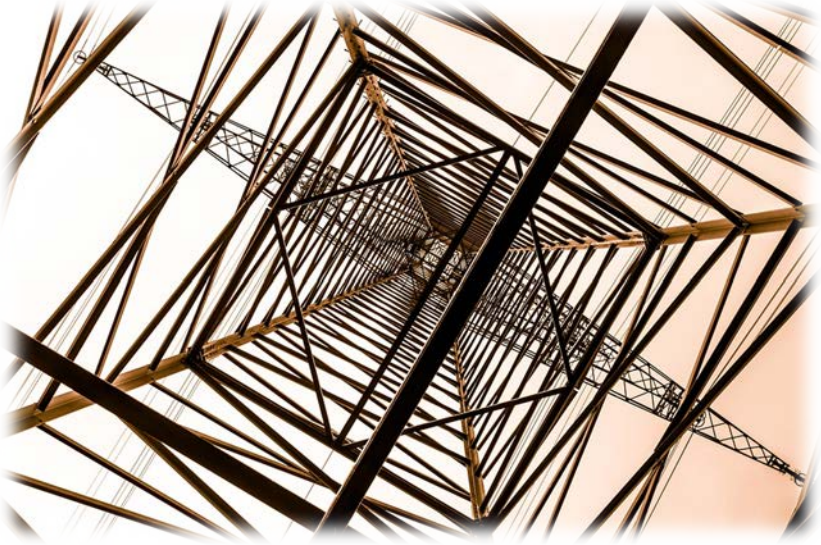
C: Steels for cold forming

D: Heat treatable steels

E: Case hardening steels

F: Nitridable steels

Other types of steels



D: Heat treatable steels

- Must be strong enough and resistant to dynamic impacts
- Fasteners, pins, joints, beam structures, wrenches, axle, cardan cross, gears, etc.
- Unalloyed and alloyed steels
- Purpose of alloying:
  - Increase the trough hardening diameter
  - Increase toughness, decrease DBTT
  - Improve fatigue resistance
  - Decrease softening during tempering

D: Unalloyed Heat treatable steels

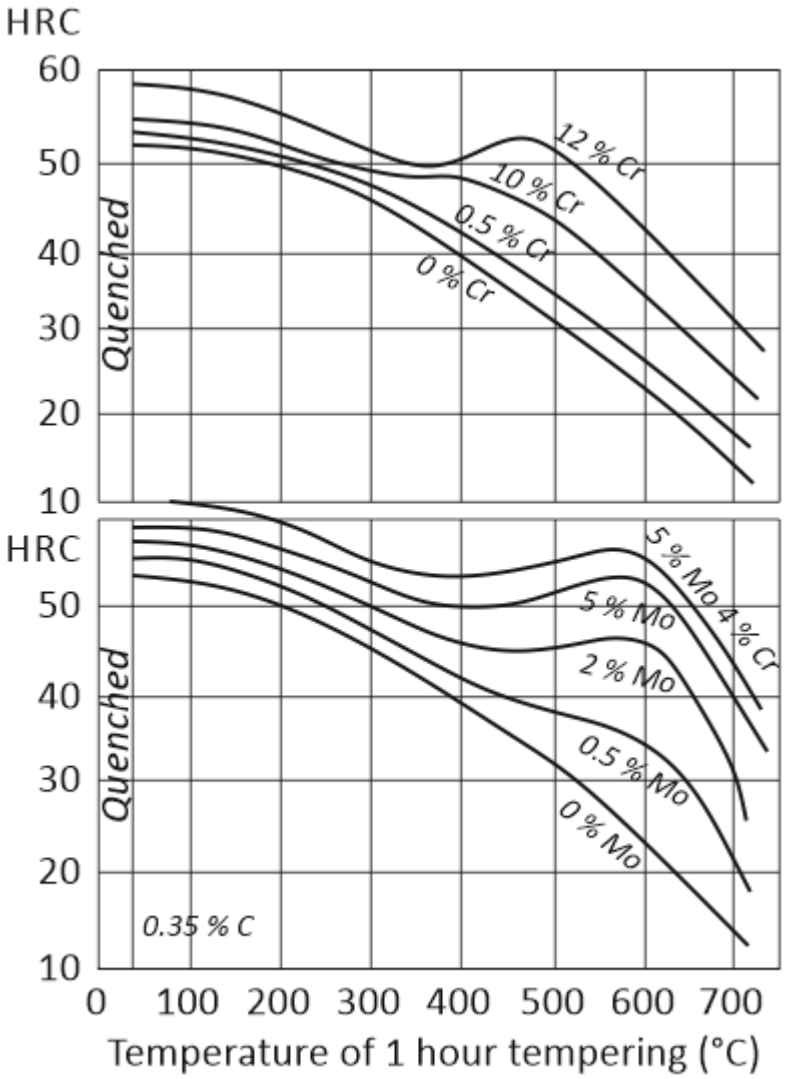
- Only carbon, no additional alloying element (except elements from production)
- Higher toughness, lower strength
- Small trough hardening diameter
- Wear resistance can be improved by surface quenching
  - R_m: 500…1000 MPa,
    R_{eH}: 300-580 MPa, A: 20-11%, Z: 50-20%
- designation: Cnn, where nn = C%
- Auxiliary marks: E: S < 0.035%,
  R: 0.020 % < S < 0.040%

D: Alloyed Heat treatable steels I.

- Mn (1.4-1.65%)
  - Cheap
  - Increased through hardening diameter
  - Susceptibility to over heating and embrittlement during tempering (fast cooling necessary)
  - Must not be used for parts with service temperature below 0°C
  - E.g.: 28Mn6

D: Alloyed Heat tretable steels II.

- Cr (up to 2%)
  - Most common alloying element
  - Strongly Increases the through hardening diameter and yield stress
  - Good surface hardenability
  - For low to middle stresses, engine parts, axles
  - E.g.: 34Cr4



D: Alloyed Heat treatable steels III.

- Cr-Mo (up to 2% Cr, 0.9-1.2% Mo)
  - Mo eliminates the embrittlement during tempering
  - Cr and Mo are strong carbide-forming elements, tempering at higher temperatures (~600°C)
  - Significant strength and good toughness
  - For middle sized part for high fatigue and impact loads.
    Axles, parts with teeth
  - E.g.: 50CrMo4

D: Alloyed heat treatable steels IV.

- Cr-V (0.7-1.1% Cr, 0.1-0.2% V)
  - Similar to Cr-Mo steels
  - A little cheaper but worse ductility
  - For middle sized part for high fatigue and impact loads.
  - E.g.: 51CrV4

D: Alloyed heat treatable steels V.

- Ni-Cr-Mo(-V)
  (0.7-1.1% Cr, 0.1-0.2% Mo)
  - Large sized parts where the fast cooling can not be realized.
  - Ni decreases the ductile to brittle temperature (DBTT)
  - Mo eliminates the embrittlement during tempering
- Through hardening diameter increases significantly (~150 mm)
- Engine parts, crankshaft, quenched & tempered state
- E.g.: 36NiCrMo16

D: Alloyed heat treatable steels VI.

- Boron steels
  - Mn, Mn-Cr alloying, B micro alloying
  - Through hardening diameter increases significantly
  - Delivered generally in hot formed state
  - Good toughness
  - E.g.: 20MnB5, 27MnCrB5-2

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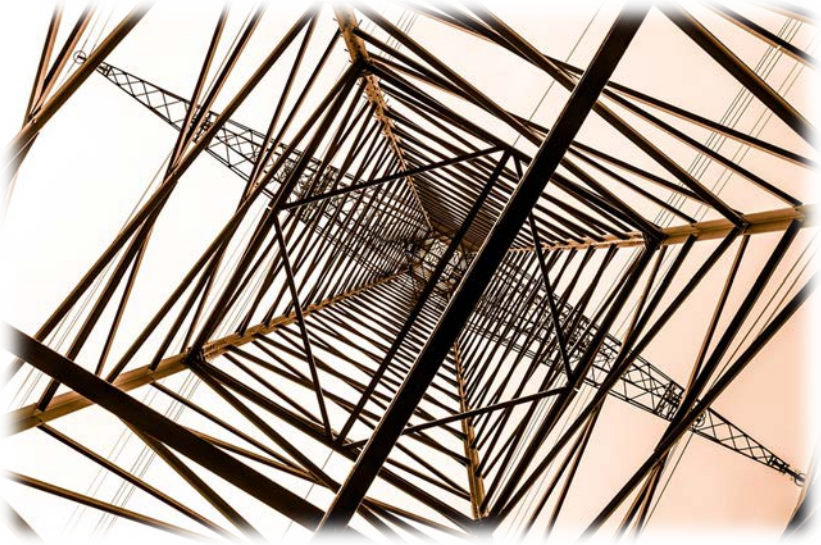


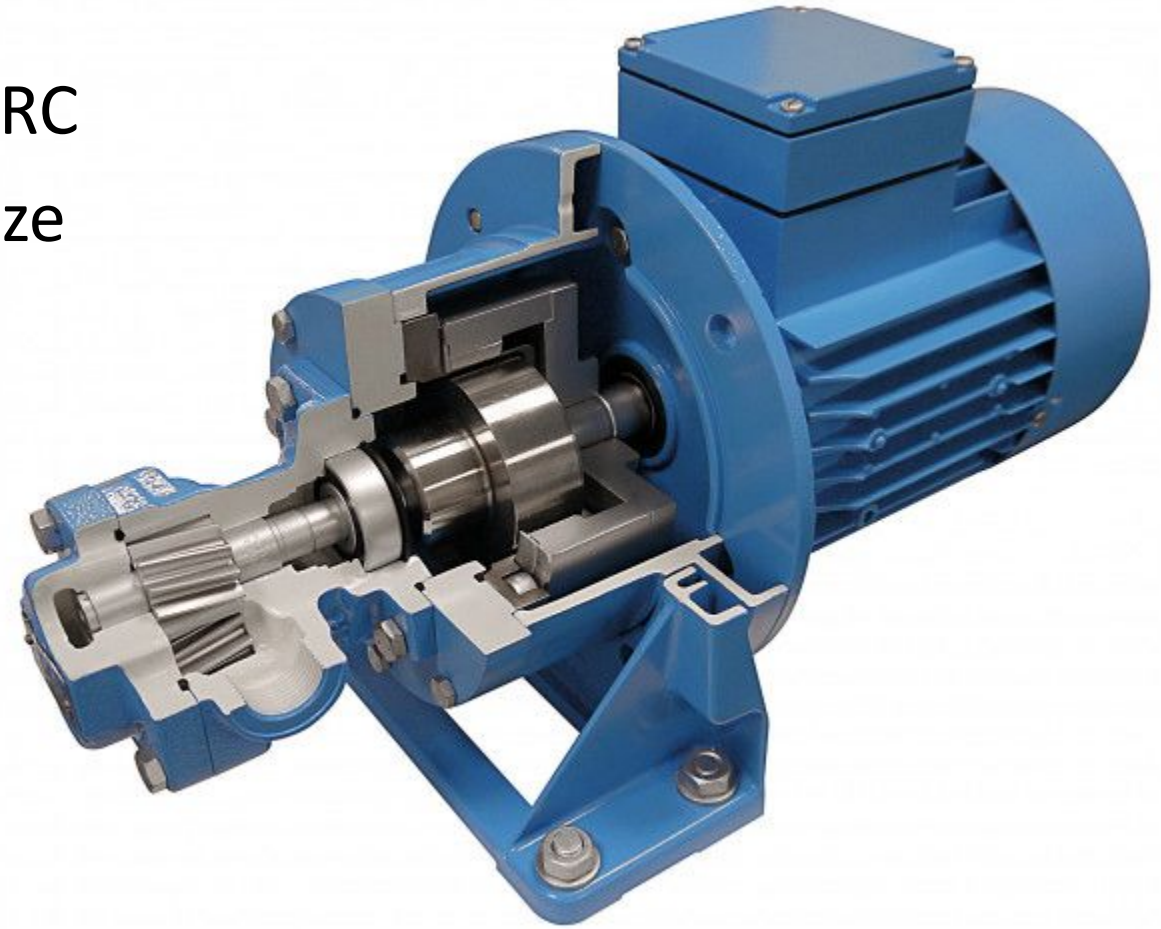
E: Case hardening steels

- Carbon content below 0.2%
- Tough core and wear resistant surface layer

  ~1% C in the surface layer, 60-63 HRC
- Can be used up to the diameter of ~80 mm (through hardenability)
- Heat treatable steels have higher strength for the same toughness
- No carburizing for fatigue loaded parts, 35-45 HRC

E: Unalloyed case hardening steels

- Small size parts for modest loads
- Pins, gear pumps
- Hardness: 55-60 HRC
- Up to 20-30 mm size
- E.g.: C10, C15



E: Alloyed case hardening steels

- Alloying elements are the same as those of heat treatable steels
- Low carbon content, C<0,2%
- Cr-Mo alloying for middle sized and loaded parts (bush, pin, gears)
  - Susceptible to overheating, up to the diameter of 40-60 mm
- Mn-Cr-Mo alloying for highly loaded parts (gears, chain wheels, axles)
  - Up to the diameter of 70-80 mm
- Ni-Cr-Mo alloying for extreme strong dynamic loads tough core, high surface hardness

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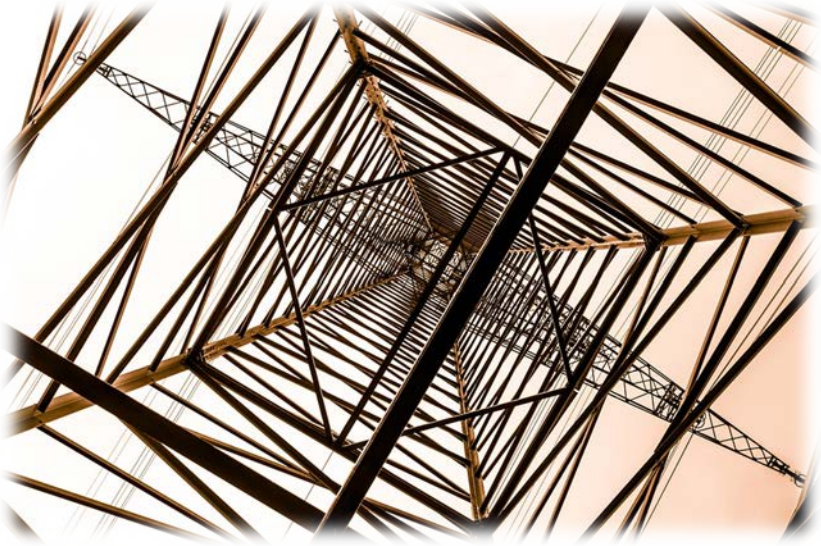

F: Nitridable steels

- They are basically heat treatable steels
- Aim: very hard wear resistant surface layer
- Addition of nitride-forming elements (Cr, Al, V, Ti)
- Results: wear-resistant, hard, better fatigue-resistance. Sensitive to high local pressures
- E.g.: 34CrAlNi7-10

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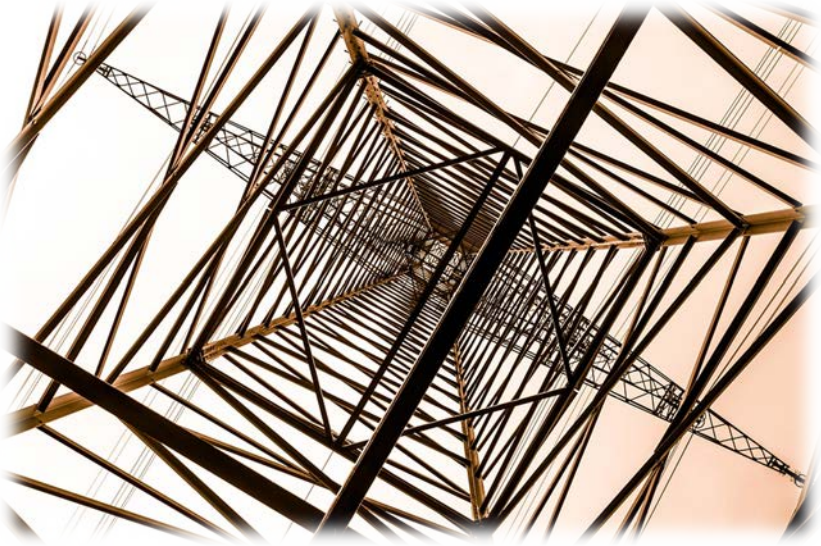
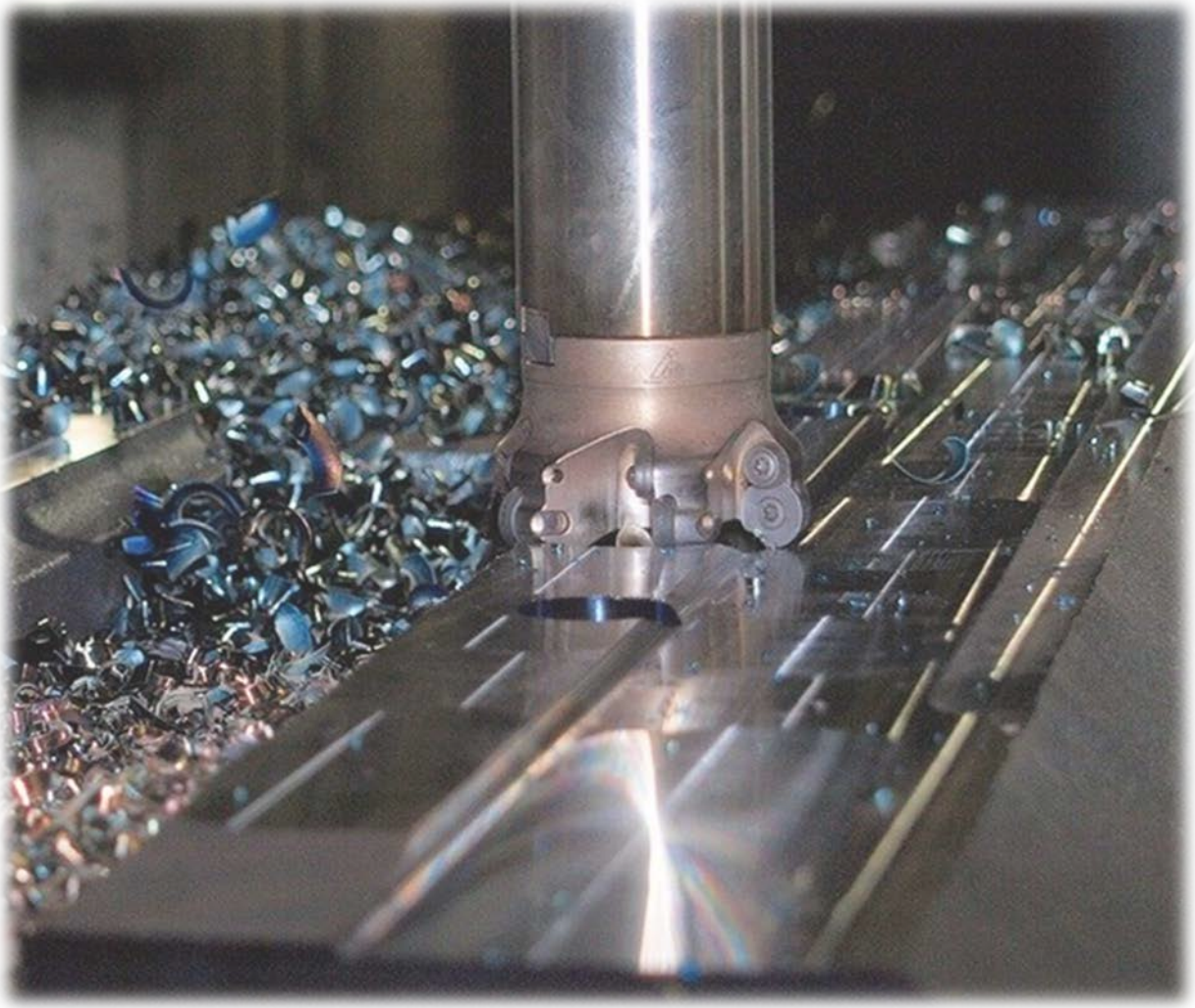


Other structural steels

- Free-cutting steels
- Steels for roll-bearings
- Spring steels
- Steels and nickel alloys for cryogenic and Low-Temperature application
- Heat resistant steels and nickel alloys
- Steels and alloys for valves of internal combustion engines

Free-cutting steels

- For high performance machining cells
- Aim: brittle chip
- S and S+Bi alloying
- E.g.: 11SMn37, 10S20, 44SMn28



Steels for roll-bearings

- High wear resistance and fatigue limit
- Carbon content 0.85-1.1% - hardness
- S < 0.015%, P < 0.025%, O < 0.,002%
- Polishing – fatigue
- Quenching, cooling to lower temp. (-30°C), low temperature tempering – 62 HRC
- E.g.: 100Cr6, 100CrMnMoSi8-4-6, 19MnCr5, 18NiCrMo14-6

Spring steels I.

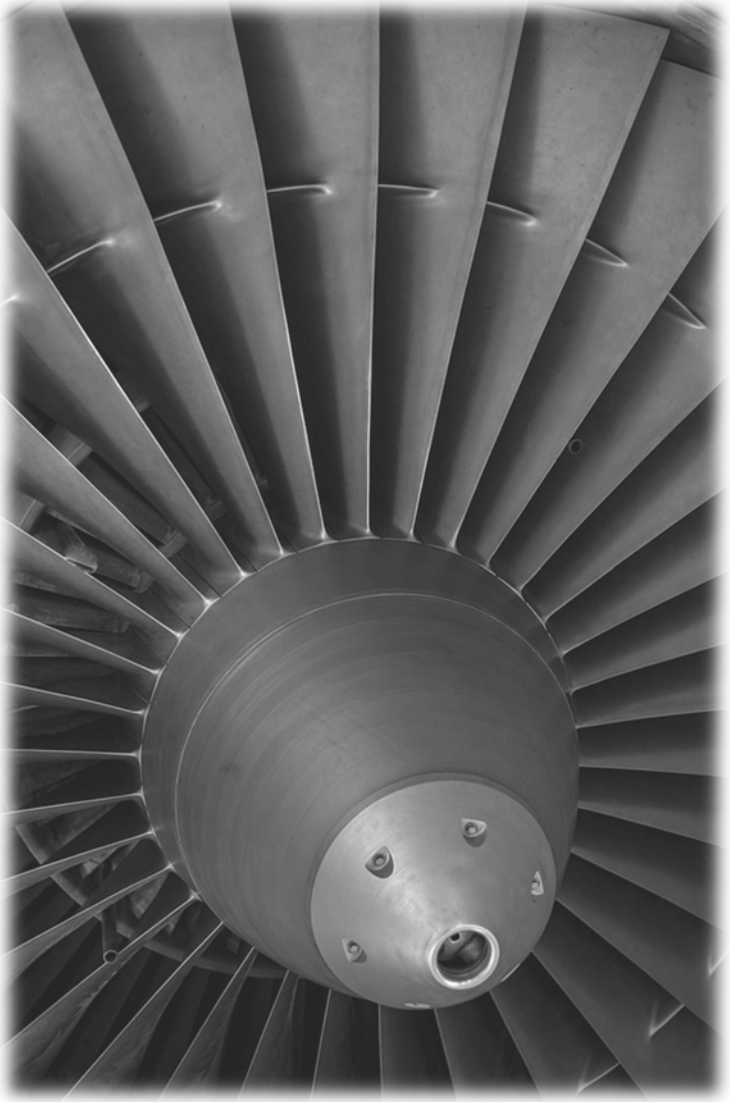
- Storing of elastic energy
- High yield stress (1000-1350 MPa) and acceptable ultimate tensile strain are necessary (6-8%)
- Heat treatable steels, 0.4-0.7% C-content, low temperature tempering (450-480°C)
- For different purposes

Spring steels II.

- Heat treated springs from hot rolled steels by forming
  - Si alloying, R_{eH} increases
  - Cr-V, Cr-MoV high performance, high dynamic loads
  - E.g.: 38Si7, 60SiCrV7, 60CrMo3-2
- Cold rolled narrow steels trip for heat treatment
  - Good surface quality, Rm up to 2100 MPa
  - E.g.: C75S
- Corrosion resistant steels strip for springs
  - For corrosive media

- Unalloyed / alloyed (corr. resistant too)
- Applicable up to 900°C
- Mo: carbide-forming increases strength
- The corrosion must be taken into account beside of heat-loading.
- E.g.: 42CrMo5-6, 25CrMo4, NiCr20TiAl (Ni alloy), X10CrNiMoMnNbVB15-10-1

- Ni alloying for low temperatures
- E.g.: 41NiCrMo7-3-2, X8Ni9, X6CrNi18-10



Heat resistant steels and Ni-alloys I.

- Problem: Oxidizing of steels' surface over 500°C
- Austenitic, ferritic, austenitic-ferritic steel
- Creep resistance and strength are the characteristic properties
- Alloying with Cr, Si, Al
- Applicable even at 900°C
- Grain coarsening can be a problem
- Ni based superalloys (not iron alloys!)

Heat resistant steels and Ni-alloys II.

- Ferritic
  - Susceptible to grain coarsening and embrittlement at 350-550°C and over 900°C, better in S-containing environment, e.g.: X10CrAlSi18
- Austenitic
  - Grain coarsening is not significant even at higher temperatures, between 600-800°C the σ-phase causes brittlement, e.g.: X10NiCrAlTi32-21
- Austenitic-ferritic
  - Not common
  - In oxidizing S-containing environment, e.g.: X15CrNiSi25-4
- Ni alloys
  - Jet engines, rocket industry, e.g.: NiCr23Fe

Steels and alloys for valves of internal combustion engines

- Homogeneous microstructure, high alloying, calculable thermal expansion
- Loads: unsteady temperature, corrosion, oxidation, fatigue, strike, wear
- Bars, wires
- Hot formable, hard to machine
- Main types
  - Martensitic valve steel e.g.: X40CrSiMo10-2
  - Austenitic valve steel e.g.: X50CrMnNiNbN21-9, NiFe25Cr20NbTi

Hadfield steels

- aka Mangalloy
- Austenitic, high alloyed Mn steels
  - ~1.2%C, ~0.4 Si, ~12.5% Mn
- Impact wear resistance, hardening during wear (cold forming)
- Inner not-hardened layer gives good toughness
- For dynamic and wear loads
- Railroad switches, excavator buckets

Corrosion resistant steels

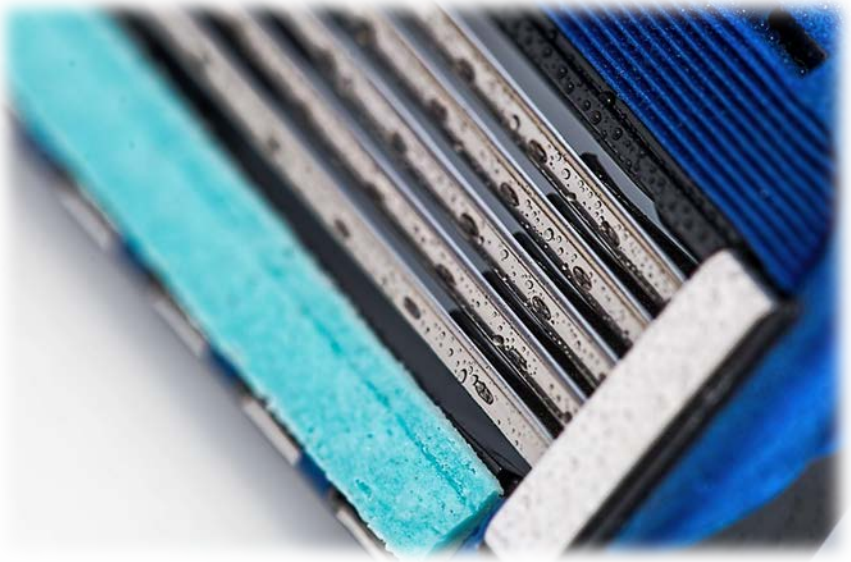
- A: Ferritic corrosion resistant steels
- B: Martensitic corrosion resistant steels
- C: Austenitic corrosion resistant steels
- D: Duplex (austenite + ferrite) corrosion resistant steels

A: Ferritic corrosion resistant steels

- The alloying element forms a cohesive, non-porous surface layer preventing the further oxidation.
- Max 0.08% carbon in ferritic corr. resistant steels and ~13% Cr
- R_{eH} ~280-320 MPa, A=18-20%
- Good formability and weldablility
- Good corrosion resistance in wear and modest corrosive media: food industry, milk industry
- For some purposes: semi-ferritic steel
  - increased strength (chemical industry)
- E.g.: X2CrTi12, X6CrMo17-1, X2CrMoTi29-4

B: Martensitic corrosion resistant steels

- Higher strenght: higher C content & heat treatment
- Heat treatment: quenching + tempering
- C content: between 0.08% and 1.2%
- Surgery blades, scalpel, needles, food industry blades
- E.g.: X12Cr13, X105CrMo17, X7CrNiAl17-7



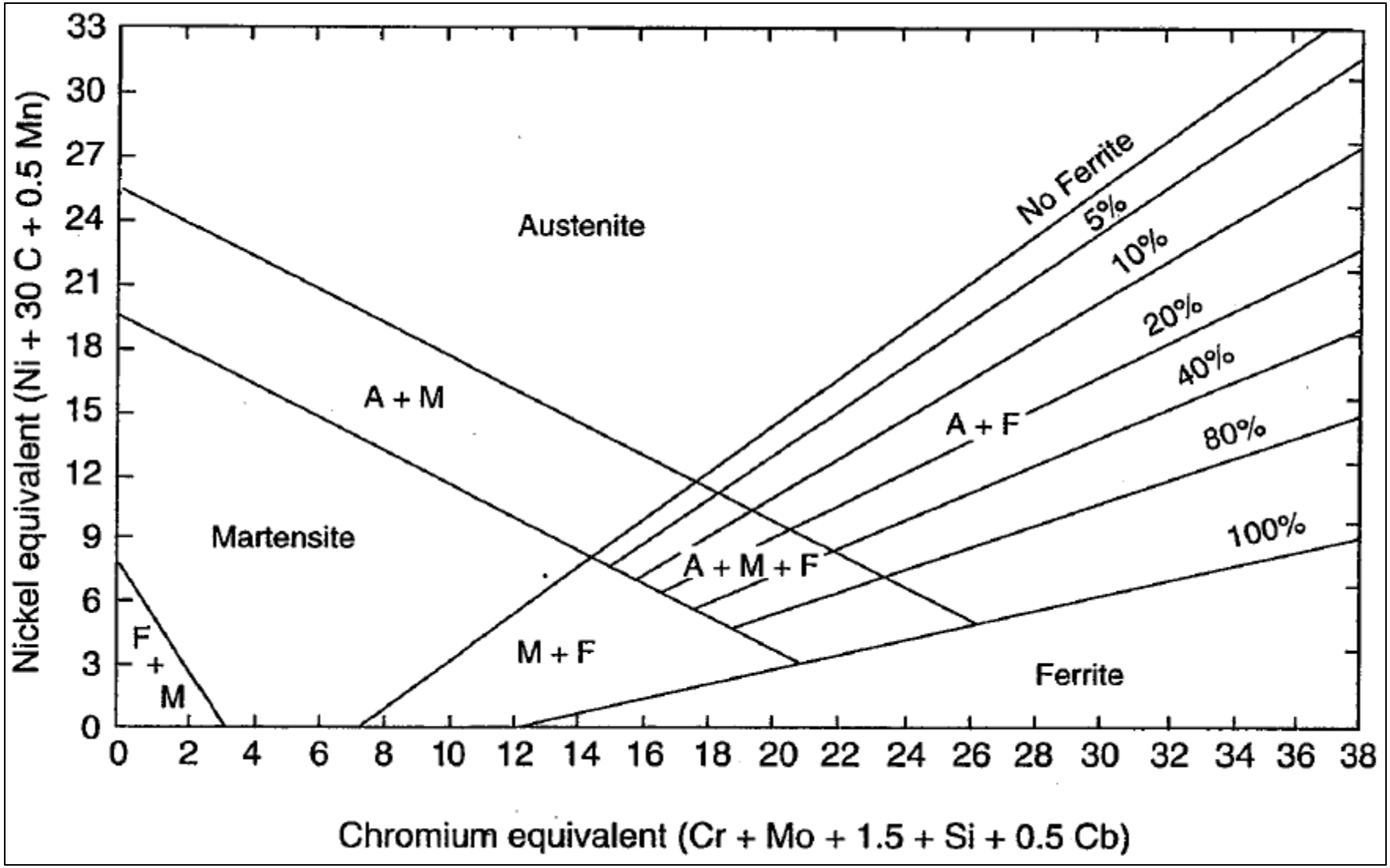
C: Austenitic corrosion resistant steels

- Ferritic corrosion resistant steels does not have good resistance against strong acids.
- Austenitic steel
- C<0.03% + ~18% Cr + ~10% Ni (Mn, Cu, N)
- Cr-cardibes form at grain boundaries by slow cooling at 600-800°C, which spoils the corrosion resistance
- Can prevent by alloying of Ti and Nb
- Difficult to machine
- E.g.: X10CrNi18-8, X3CrNiMo17-13-3

D: Duplex corrosion resistant steels

- High Cr and Ni content
- ~40-60% austenite at room temperature
- Higher strength
- Better stress-corrosion resitance
- Some grades can be applied as heat resistant steel as well.
- E.g.: X2CrNiN23-4, X2CrNiMoCuWN25-7-4

Corrosion resistant steels



Tool Steels

- A: Unalloyed tool steels
- B: Hot forming tool steels
- C: Cold forming tool steels
- D: High speed steels

https://cdn.thefabricator.com/a/plate-rolling-gets-hot-1502110780.jpg?size=1000x

General requirements

- Hardness, wear resistance
- Toughness
- Heat resistance
- Resistance against thermal fatigue
- Appropriate through hardening diameter

A: Unalloyed tool steels

- 0.45-1.25% C content
  - 0.45% C – 54 HRc
  - 1.25% C – 62 HRc

- Only base alloying and impurity elements (Mn, Si, S, P)
- For hand tools
- E.g.: C90U, C100U
  - U mark: un-treated state

B: Hot forming tool steels

- Service temperature over 200°C, but hardness and heat resistance even at 600°C (38-46 HRc)
- Main alloying elements: Cr, Mo, W, Ni, Co
- Carbide compounds– hardness at high temperatures
- Closed-dies for forging, die-casting dies
- E.g.: 55NiCrMoV7, X40CrMoV5-1

C: Cold forming tool steels

- Main alloying elements: Mn, Cr, Mo, V, W, Ni
- To increase through hardening diameter and improve
  - Strength
  - Wear resistance
  - Hardness

- Heat-treated. Service temperature at room temperature (maximum 150-180°C)
  - E.g. Cutting and punching tools
  - E.g.: 95MnWCrV5, X210CrW12

E: High speed steels

- For high performance machining. 62-64 HRc hardness at ~600°C
- Main alloying elements : W, Mo, V, Co
- Special heat treatment methodology (precipitation hardening)
- E.g.: HS6-5-2, HS10-4-3-10

Thank you for your attention!