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

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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 %

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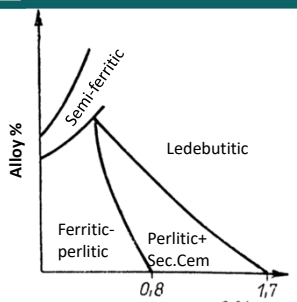
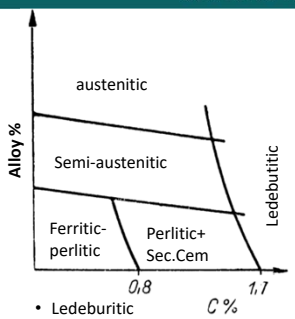
Structure at room temperature



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



- Ledeburitic
- Semi austenitic
- Austenitic
  - Austenite promoting element

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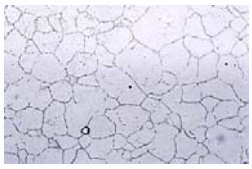
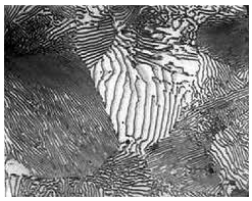
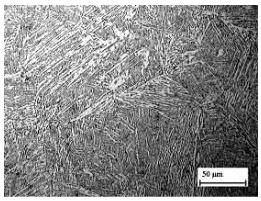
Structure at room temperature



- Perlitic
- Martensitic
- Austenitic
- Ferritic
- Bainitic





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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.

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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**

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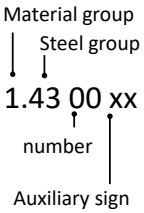
Designation of steels

Example: number (werkstoffnummer)



1 – steels
2 – heavy metals
3 – light metals
4 – nonmetallic
…
8 – nonmetallic
9 – rest

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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)	
…	…	…	…

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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

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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

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Structural steels

A: hot rolled structural steels

B: flat steel products for pressure vessels
Formability, weldability

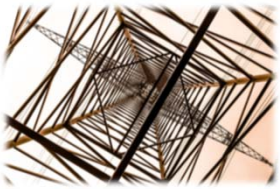
C: Steels for cold forming

D: Heat treatable steels

E: Case hardening steels

F: Nitridable steels

Other types of steels



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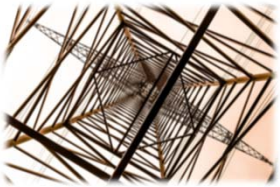

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A: Hot rolled unalloyed structural steels

- 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

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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

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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

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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

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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

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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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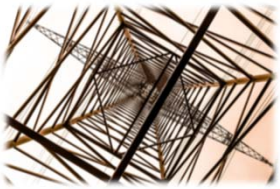

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B: Plain and alloyed steels for elevated temperatures

- 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

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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

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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

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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

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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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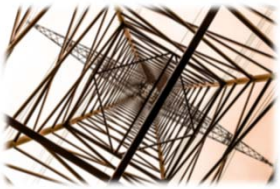

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C: Cold rolled flat products from low carbon steels for cold forming

- 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

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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

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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

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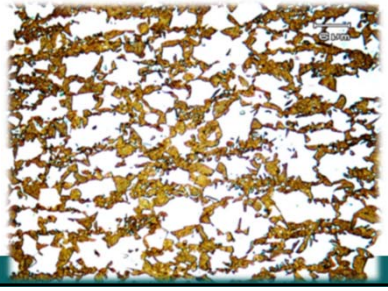
Dual Phase steels

- 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

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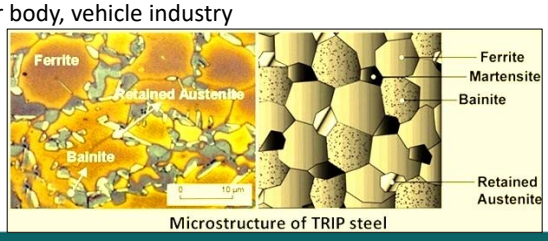
Transformation Induced Plasticity steels

- 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/

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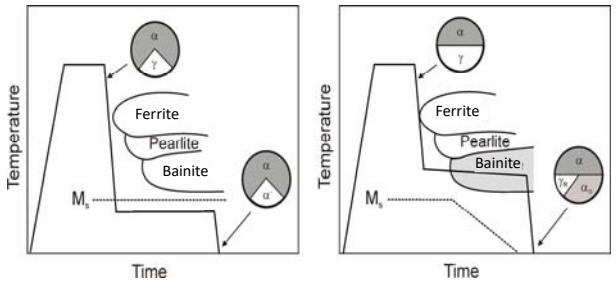
DP / TRIP treatment



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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

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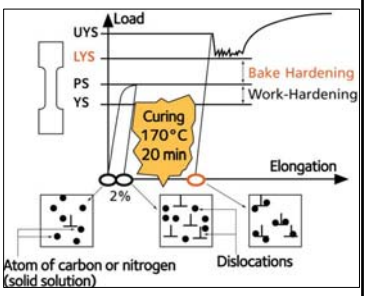
Bake Hardening steels

- 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

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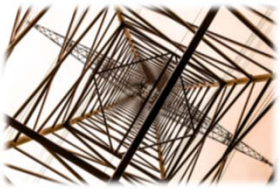

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D: Heat treatable steels

- 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

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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%

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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

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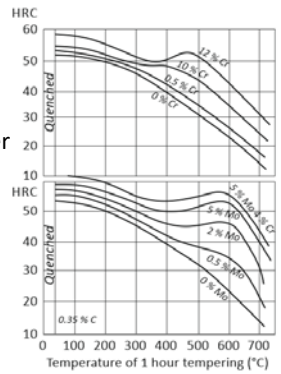
D: Alloyed Heat tretable steels II.

- 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



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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

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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

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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

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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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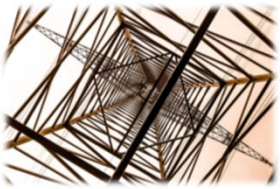

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E: Case hardening steels

- 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

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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

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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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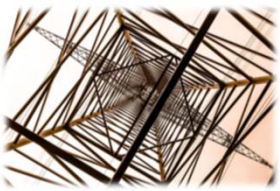

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F: Nitridable steels

- 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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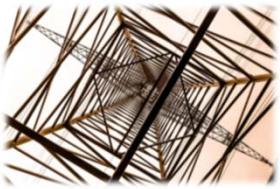

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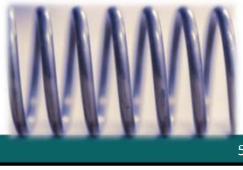
Other structural steels

- 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



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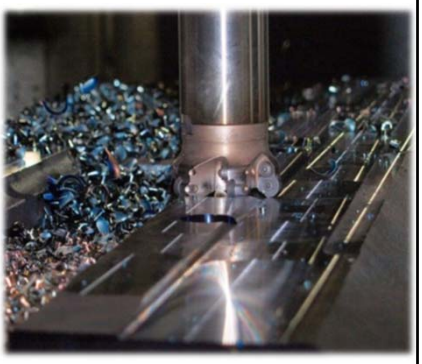
Free-cutting steels

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



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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

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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

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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

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Steels and nickel alloys for cryogenic, low-temperature and heat resistant application

- 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

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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!)

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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

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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

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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

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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


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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

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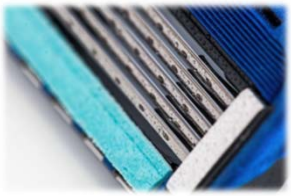
B: Martensitic corrosion resistant steels

- 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



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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

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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

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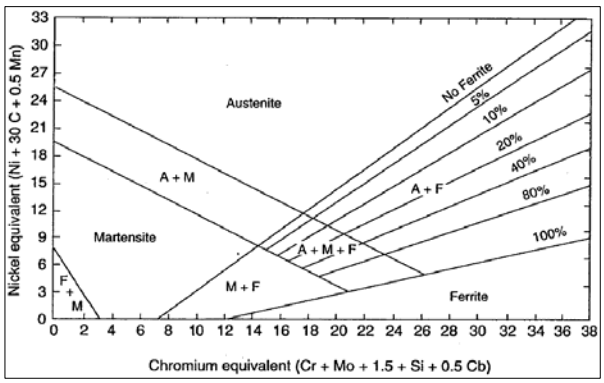
Corrosion resistant steels



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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

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General requirements

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

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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

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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

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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

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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

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Thank you for your attention!

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