ALLOY STEELS. CLASSES.
INFLUENCE OF ALLOYING ELEMENTS.
STRUCTURAL ALLOY STEELS.
STEELS WITH SPECIAL PROPERTIES.
ALLOY TOOL STEELS.
ALLOY STEELS = Complex Fe-base alloys;
main alloying element - C (max. 2%);

other elements introduced for improving of certain properties
mechanical
physical (magnetic, thermal)
chemical (corrosion resistance)

technological (hardenability, weldability, ...).
Influence of alloying elements in steels

1. Influence upon Fe allotropic transformations

Gammagene elements: enlarge the existence domain of Feγ (austenite)
In large amounts – austenite at room’s temperature

Ni, Mn

Alphagene elements:
Narrow the existence domain of Feγ, enlarging the Feα (ferrite) one
In large amounts – mainly ferritic structure

Cr, Mo, W, V, Al, Si, Ta, ...
Influence of alloying elements in steels

2. Influence upon carbon

Carbide – forming elements
(form carbides and alloy cementites)

Mo, W, V, Cr, Ti,... (alphagene) + Mn (gammagene)

Graphitizing elements

Si, Al, Cu, Ni
Influence of alloying elements in steels

3. Influence upon properties

Ferrite strength increased by adding Mn, Si, Ni,...

The growth tendency of austenite grain

*decreases* by adding Mo, W, Cr, ...

*increases* by adding Mn

Hardenability increases through alloying (Co - exception);

maximum effect: Mn
Classes of alloy steels

A. According to the alloying degree
   - low alloy (content of alloying elements < 5%)
   - high alloy (content of alloying elements > 5%)

B. According to the use
   - structural
   - tools
   - special properties (physical, chemical, ...)
   - special destination (boilers, rails, ....)
Main alloying elements in steels

Chromium

Alphagene, carbide-forming element
Decreases the overheating tendency
Increases strength, toughness, elasticity, hardness, wear resistance
Increases hardenability
For more than 12% dissolved in a solid solution – stainless steel

Nickel

Gammagene element
Increases hardenability
Increases toughness, strength, corrosion resistance
Main alloying elements in steels

**Manganese**

Gammagene element
Forms carbides that are soluble in cementite
Increases hardenability a lot, wear resistance, weldability
Increases the overheating tendency!

**Tungsten**

Alphagene, strong carbide-forming element
Increases strongly hardness
Decreases strongly the size of the austenite grain
but, also, toughness – not alone
Main alloying elements in steels

Molybdenum

Alphagene, stronger carbide-forming element than W
Very fine structure, good hardenability, high fatigue resistance

*Decreases the tendency for tempering embrittlement*
Increases the recrystallization temperature

Vanadium

Alphagene, excessive carbide-forming element
Increases hardness, *elasticity, fatigue resistance*
**Structural alloy steels**

Low alloy steels (under 2.5% alloying elements, generally)
Display structures resembling the corresponding ones of unalloyed steels

**Carburizing alloy steels**

Carbon content: 0.06 – 0.25%

Steels with Cr (max. 1.5%)
Cr – Mn (max. 1% Mn for hardenability)
Cr – Ni (~ 1% Cr, max. 4% Ni) – bainitic core

**Standardization**

SR EN 10028 – 1:1996  **N E₁E₂ N₁ (– N₂)**

N - carbon content (hundredths of percent); Ex. 14NiCr12-5 (~3%Ni, 1.25%Cr)

E₂, E₁ – alloying elements in the order of decreasing the importance;
N₁, (N₂) – content of elements E₁, E₂ x f; f – factor = 4/10 [/100 / 1000]

<table>
<thead>
<tr>
<th>Element</th>
<th>Cr, Co, Ni, Mn, Si, W</th>
<th>Al, Be, Cu, <strong>Mo</strong>, Nb, Pb, Ti, Ta, V, Zr</th>
<th>Ce, N, P, S</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>10</td>
<td>100</td>
<td>1000</td>
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</tbody>
</table>
Structural alloy steels
Alloy steels for quenching and tempering

Carbon content: 0.25 – 0.6%

Standardization
SR EN 10083 – 1:1994

N - carbon content (hundredths of percent); E₂, E₁ – alloying elements in the order of decreasing the importance; N₁(N₂) – content of element E₁ (E₂) x f

Steels with Cr, Cr-Mo allow oil quenching; Ex. 40Cr4, 42CrMo4
Mn increased hardenability (and overheating tendency); Ex. 35Mn16
Cr - Ni high strength after HT tempering embrittlement
a. 200 – 400°C partial Ar – M transformation
b. 500 – 600°C P diffusion avoiding: Cr-Ni-Mo
Cr – V fine structure and high elasticity; Ex. 51CrV4
HIGH STRENGTH LOW – ALLOY STEELS (HSLA)

Generally: steels with < 0.25%C, < 2% alloying elements

Mn + Cu, Ti, V, Nb, … - increase of strength through fineness of structure

Cu, Si, Ni, P, … – increase corrosion resistance
(micro-alloying also)

- Requirements related to mechanical properties, weldability
- Corrosion resistance

$R_m = 415 – 700 \text{ MPa}; \ R_{p_{0.2}} = 275 – 550 \text{ MPa}$

Ex. ASTM :
A 242 – 0.15%C, 1%Mn, 0.15%P, 0.2%Cu: \ $R_m = 435 – 485 \text{ MPa}$
A 633 C – 0.2%C, 1.15-1.5%Mn, 0.15-0.5%Si, 0.01-0.05%Nb: \ $R_m = 450 – 620 \text{ MPa}$
A 710 B – 0.06%C, 0.4-0.65%Mn, 0.2-0.35%Si, 1.2-1.5%Ni, 1-1.3%Cu, >0.02%Nb: \ $R_m = 605 – 620 \text{ MPa}$
HSLA FOR QUENCHING AND TEMPERING

Generally: HSLA with < 5% alloying elements

High strength, ductility, toughness, corrosion resistance, weldability

Quenching + Tempering >>> martensite, bainite [+ferrite]

Some classes: precipitation hardening after rolling / quenching

Rp\textsubscript{0.2} = 345 – 895 MPa; Rm = 485 – 1035 MPa

Ex. ASTM
A 514 A – 0.15-0.21%C, 0.8-1%Mn, 0.4-0.8%Si, 0.5-0.8%Cr, 0.18-0.28%Mo, 0.05-0.15%Zr, 0.0025%B: Rm = 700 – 895 MPa;
A 517 Q – 0.14-0.21%C, 0.95-1.3%Mn, 0.15-0.35%Si, 1-1.5%Cr, 1.2-1.5%Ni, 0.4-0.6%Mo, 0.03-0.08%V: Rm = 725 – 930 MPa
UHSLA

Steels with $R_{p0.2} \text{ min} = 1240 \text{ MPa}$, $R_m \text{ min} = 1380 \text{ MPa}$

+ toughness

Generally: Ni-Cr-Mo-V or Ni-Co

Ex. ASTM:
AMS 6432 – 0.31-0.38%C, 0.6-0.8%Mn, 0.2-0.35%Si, 0.65-0.9%Cr, 1.65-2%Ni, 0.3-0.4%Mo, 0.17-0.2%V;
HP 9-4-30 0.3%C, 1%Cr, 7-8%Ni, 1%Mo, 4.25-4.75%Co;
Advanced high strength sheet steels, automotive
Advanced high strength sheet steels (AHSS) – First generation

**Ferrite – based structures:**

**DP (Dual Phase)**
ferrite with martensite isles

**TRIP (Transformation Induced Plasticity)**
ferrite + austenite >>> martensite through deformation

**CP (Complex – Phase)**
very fine complex structure (austenite, ferrite, pearlite, martensite)

**MART (Martensitic)**
Oteluri avansate de mare rezistenta, tabla (AHSS) – Second generation

Austenitic steels with high amount of Mn:

TWIP (Twinning – Induced Plasticity)
>20%Mn, deformation twinning

L – IP (Al-added lightweight with induced plasticity)
<4%Al

SIP (shear band strengthened)
Martensite with nano-twinning
Structural alloy steels
Alloy steels for quenching and tempering

Special structural steels

- **Bearings steels:**
  - 1%C, 1.5%Cr, Mn (more for heavy bearings), Si

- **Spring steels:**
  - Unalloyed: 0.55 – 0.85%C (weak loading)
  - Alloy with Si: best R / A ratio for average loading
  - with **Cr and V** for heavy loading;
Steels with special physical – chemical properties

High alloy steels (content of alloying elements > 5%)

Symbolization

\[ X \ N \ E_1E_2 \ N_1 - N_2(-N3) \]

N - carbon content (hundredths of percent);
E₂, E₁ – alloying elements in the order of decreasing the importance;
N₁, N₂ – content of elements E₁, E₂ in percents

Ex. X 5 CrNi 18-10

(+ G for cast steels); Ex. G X 10 CrNi 18-8

SR EN 10027 – 1:1996
Steels with special physical – chemical properties - Stainless steels

Steels that withstand corrosion (atmosphere and other environments)

Contain more than 12% Cr dissolved in a solid solution
(austenite, ferrite, martensite)

Corrosion resistant due to a Cr₂O₃ protective layer

According to the *normalization structure*

- **Austenitic**  Cr-Ni  best corrosion resistance
- **Martensitic** Cr – Ni self-hardening, maximum R
- **Ferritic**  Cr (over 13%), cheapest
Stainless steels

*Schaeffler Diagram*:
structure of stainless steels after air cooling from 1000°C
Steels with special physical – chemical properties

Refractory steels

Steels that resist high temperatures (maximum 650 – 700°C, generally)

Refractoriness =

- stability of mechanical properties
- structural stability: elements forming intergranular carbides
- chemical stability: elements which form protective oxide layers
  - Cr, Al, Si

According to the normalization structure:

**Austenitic**  Cr-Ni, more carbon than in stainless steels
  + stabilizing elements (form stable carbides): Ti, Mo, ...

**Martensitic**  Cr – Ni + Al, Mo, Si

**Ferritic (with carbides)**  Cr (up to 30%)
  - cheap, low strength
Steels with special physical – chemical properties
Highly wear resistant steels (Hadfield)

Cast steels containing a high amount of Mn (11.4 – 14.5%)

Overheated austenitic structure
Strong cold hardening during wear
Alloy tool steels

**Tools:** wear resistant, machining, cold / hot forming, wrenches, ...

**Required properties**

- high hardness (up to 65 HRC)
  - $\rightarrow$ carbide-forming elements
    - (+martensitic structure)
- wear resistance
- toughness
- hot structural stability (500 – 600°C) – W, Mo, Si, ...
Alloy tool steels

Forming tools
cold – high amount of Cr and C, fine martensite; Ex. 102Cr6, X210Cr12
hot – fine sorbitic structure + carbides; Ex. 38CrCoWV18-17-17, X30WCrV9-3

High speed steels – allow machining rates up to 400 m / min.
(600 – 700°C work temperature)
0.8 – 1.4% C; 5 – 18%W; Mo up to 5% for replacing W;
~ 4% Cr, 1 – 4% V

Typical: 0.75% C, 18% W, 4% Cr, 1% V
Symbolization: HS + percentage of W-Mo-V-Co; Ex. HS18-0-1

Utilization structure: fine tempering martensite + carbides
Alloy tool steels

Fig. 15B. Microstructura oțelului rapid Rp 3 (cu 18% W);
- a — turnat 100 : 1; b — forjat și receopt (500 : 1);
- c — călit (1000 : 1).
Glossary

- Oțel aliat = alloy steel;
- Element alfagen / gamagen = gammagene / alphagene element;
- Element carburigen = carbide-forming element;
- Carbură = carbide;
- Oțel slab / înalt aliat = low / high alloy steel;
- Fragilizare = embrittlement;
- Oțel de constructie = structural steel;
- Rulment = (ball) bearing;
- Arc = spring;
- Oțel inoxidabil = stainless steel;
- Autocălibil = self (air) – hardenable;
- Oțel refractar = refractory steel;
- Oțel rezistent la uzare = Hadfield / austenitic manganese steel;
- Oțel de scule = tool steel;
- Oțel rapid = high speed steel;