HIGH-ALLOY STEELS: STAINLESS STEELS (SS)

- The primarily-alloying element is Cr (≥11 wt.%)
- Highly resistance to corrosion;
  - Nickel and molybdenum additions increase corrosion resistance
- A property of great importance is the ability of alloying elements to promote the formation of a certain phase or to stabilize it.
  - These elements are grouped as three major classes:
    1. austenite-forming,
    2. ferrite-forming,
    3. carbide-forming and

DISTRIBUTION OF ALLOYING ELEMENTS IN STEELS.

- Alloying elements can influence the equilibrium diagram in two ways in ternary systems Fe-C-X.

1. Expanding the γ -field, and encouraging the formation of austenite over wider compositional limits. These elements are called **γ -stabilizers**.

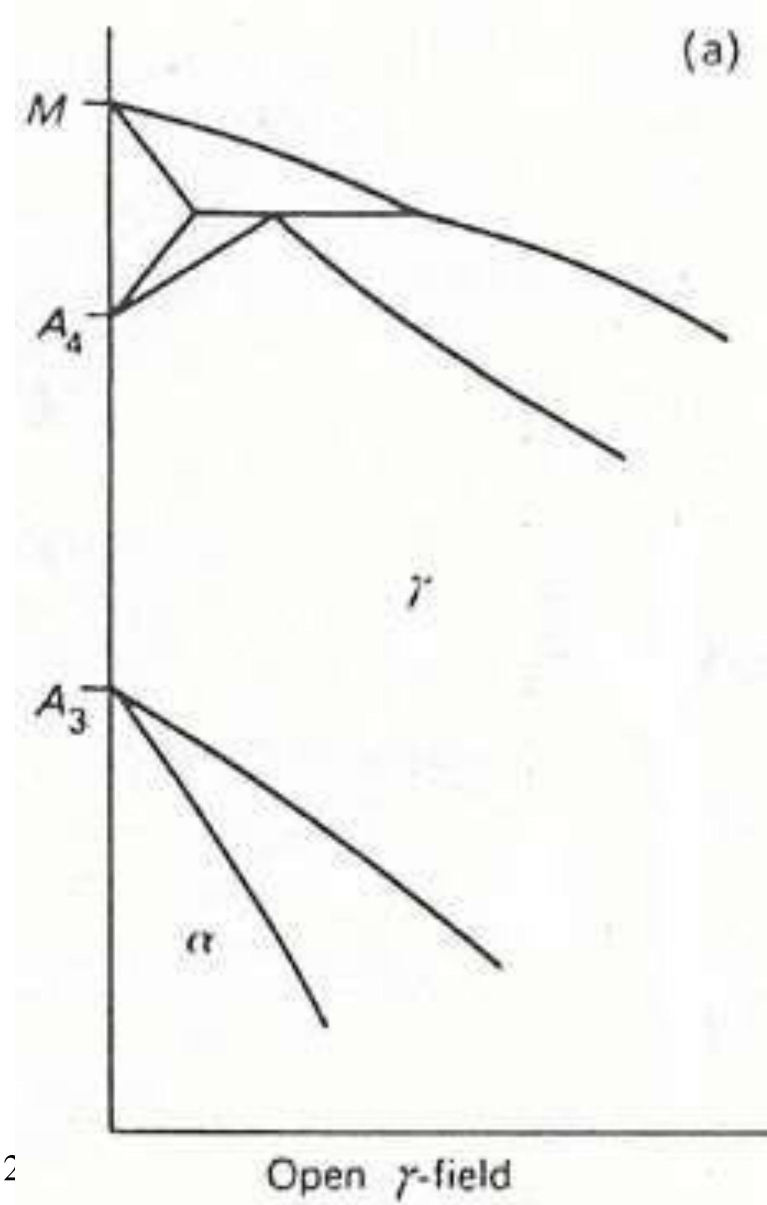
2. Contracting the γ-field, and encouraging the formation of ferrite over wider compositional limits. These elements are called **α-stabilizers.**

A. OPEN γ - FIELD: AUSTENITIC STEELS.

- Nickel and manganese depress the phase transformation from γ to α to lower temperatures

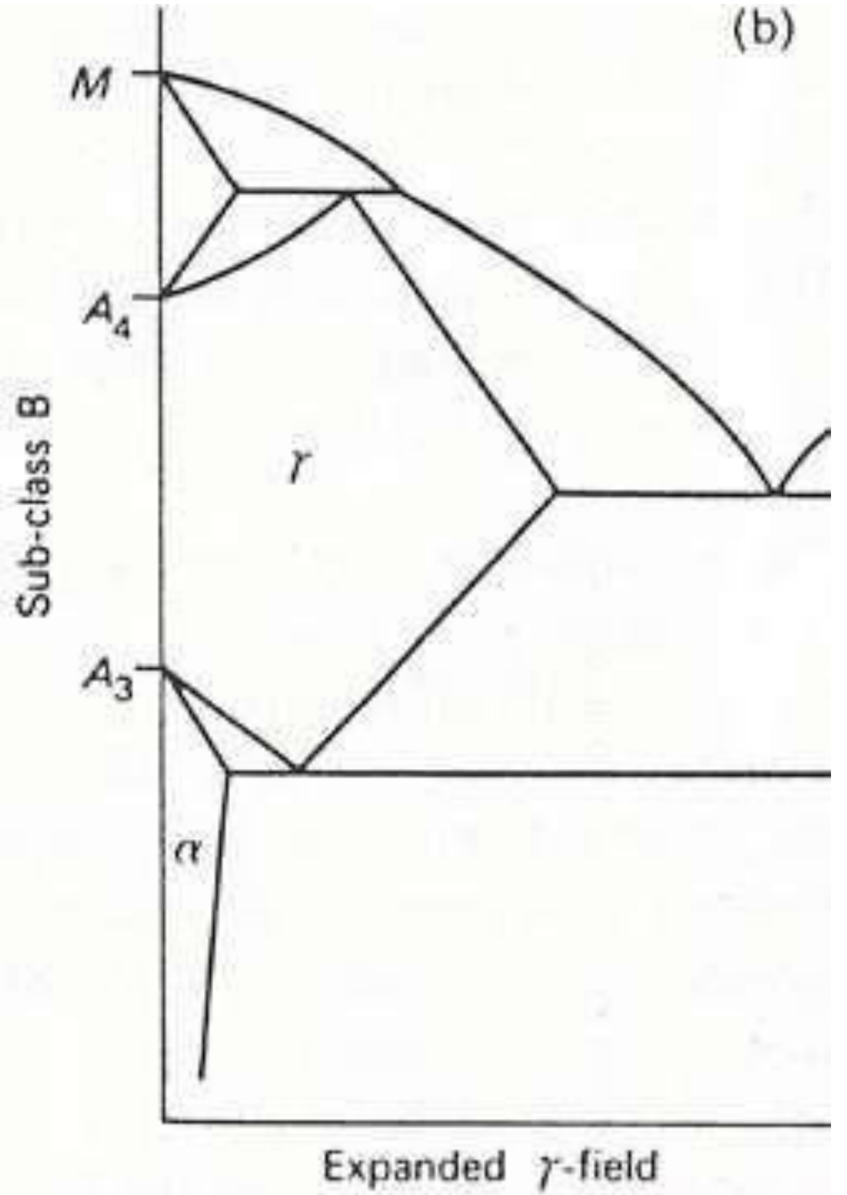
- both Ac_1 and Ac_3 are lowered.

- It is also easier to obtain metastable austenite by quenching from the γ-region to room temperature



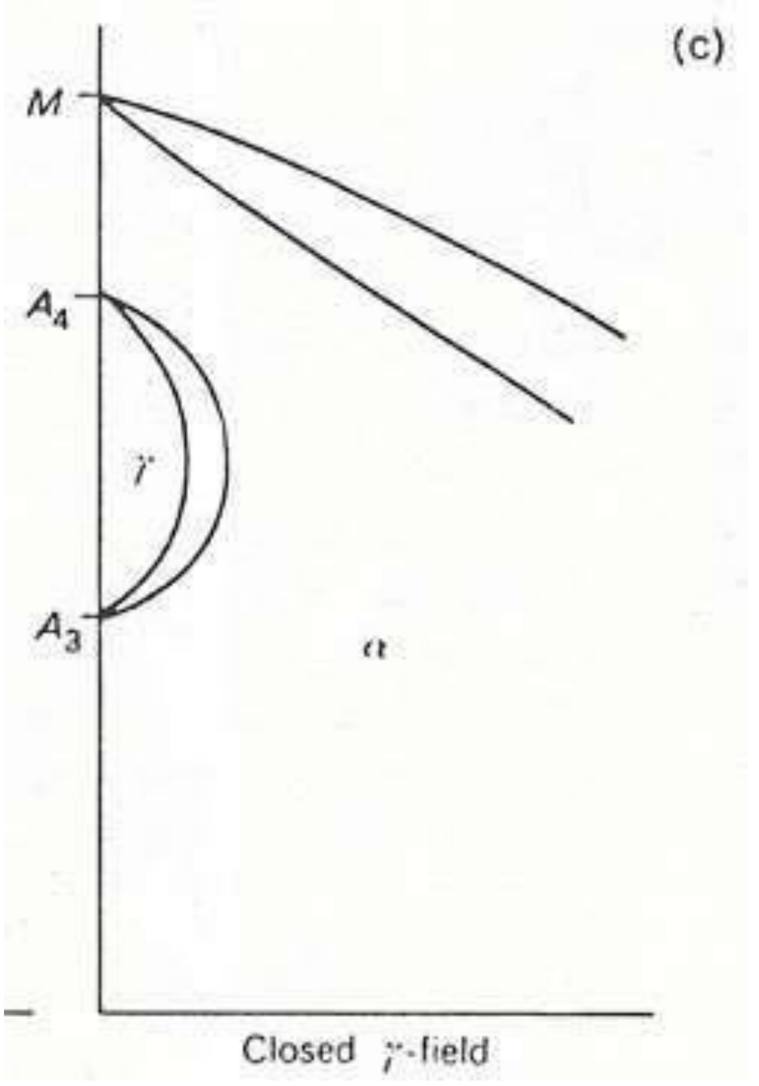
B. EXPANDED γ -FIELD : AUSTENITIC STEELS

- Carbon and nitrogen (Copper, zinc and gold)
- The γ-phase field is <u>expanded</u>
- Heat treatment of steels,
  - allowing formation of a homogeneous solid solution (austenite) containing up to 2.0 wt % of carbon or 2.8 wt % of nitrogen



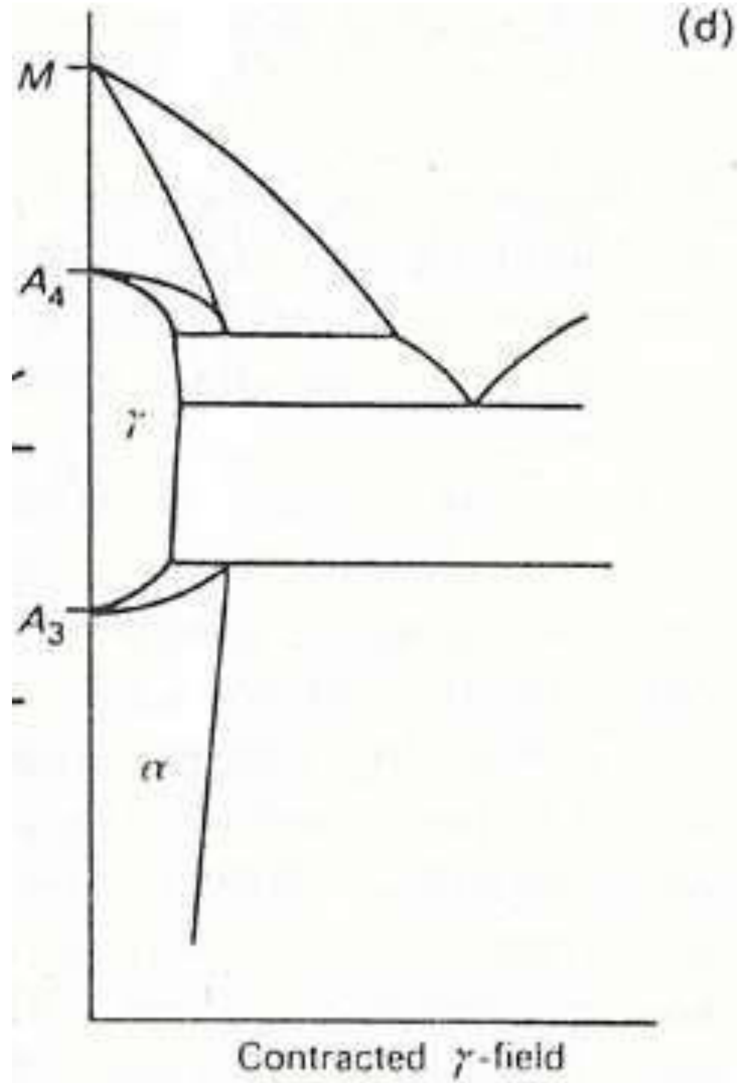
C. CLOSED γ -FIELD : FERRITIC STEELS

- Silicon, aluminium, beryllium and phosphorus (strong carbide forming elements - titanium, vanadium, molybdenum and chromium)
- γ-area contract to a small area referred to as the gamma loop
  - encouraging the formation of BCC iron (ferrite),
- Not amenable to the normal heat treatments involving <u>cooling through the γ/α-phase transformation</u>

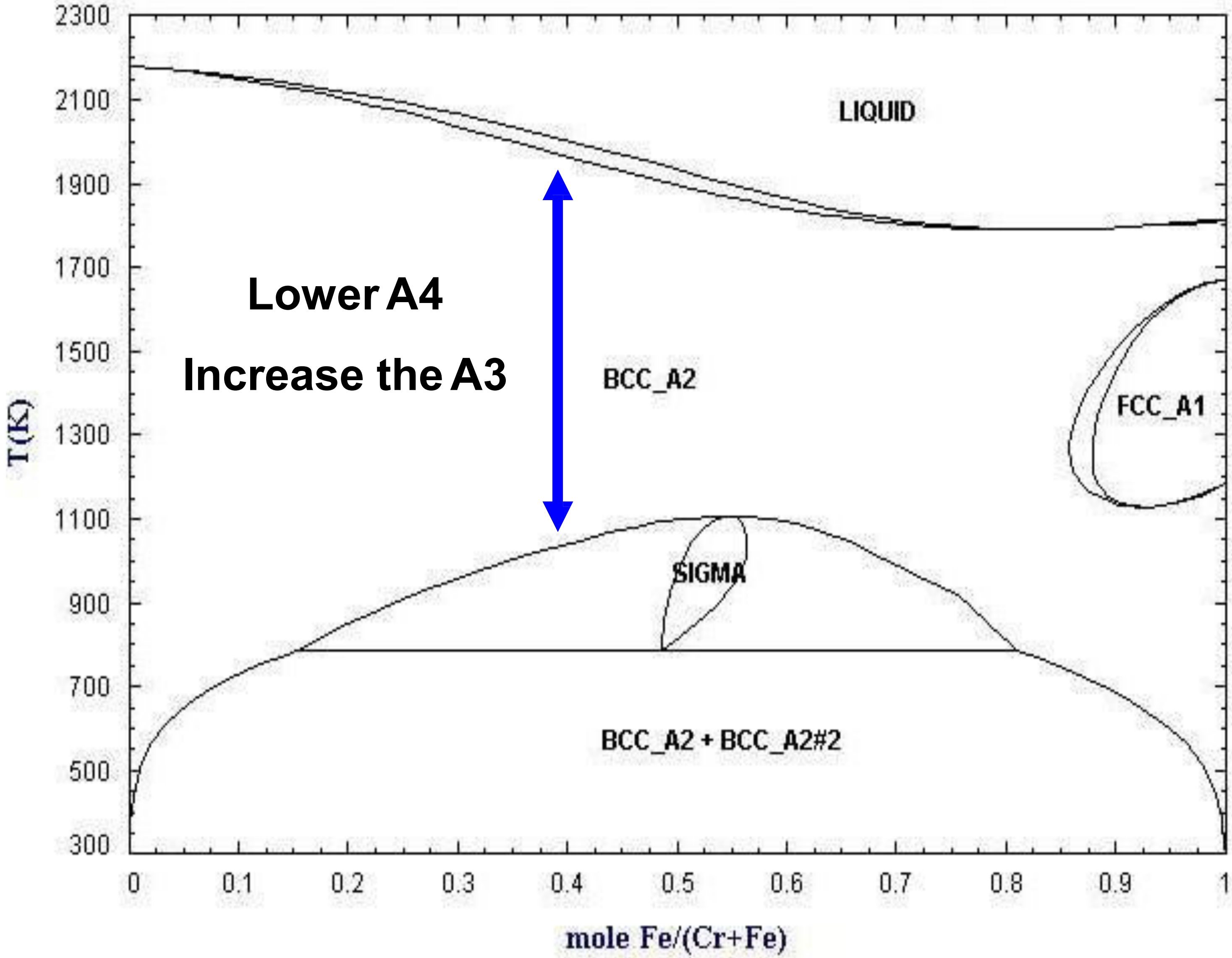


D. CONTRACTED γ -FIELD : FERRITIC STEELS

- Boron is the most significant element of this group (carbide forming elements - tantalum, niobium and zirconium.
- The γ-loop is strongly contracted
- Normally elements with opposing tendencies will cancel each other out at the appropriate combinations, but in some cases irregularity occur. For example, chromium added to nickel in a steel in concentrations around 18% helps to stabilize the γ-phase, as shown by 18Cr8Ni austenitic steels.



Cr-Fe equilibrium diagram



EFFECT OF ALLOYING ELEMENTS

- Rule of thumb: Chromium (Cr) makes steel **hard** whereas Nickel (Ni) and Manganese (Mn) make it **tough**.
- Note that:
  - 2% C, 12% Cr tool steel grade- very hard and hard-wearing
  - 0,10% C and 12% Cr- Modest hardening
  - 13% manganese steel, so-called Hadfield steel
    - increases steel toughness
  - Mn between 1% and 5%, however - toughness may either increase or decrease

EFFECT OF MAGNESSIUM (M)

$^{25}Mn_{54.938049}$

Manganese increases hardenability and tensile strength of steel, but to a lesser extent than carbon. It is also able to decrease the critical cooling rate during hardening, thus increasing the steels hardenability much more efficient than any other alloying elements. Manganese also tends to increase the rate of carbon penetration during carburizing and acts as a mild deoxidizing agent. However when too high carbon and too high manganese accompany each other, embrittlement sets in. Manganese is capable to form Manganese Sulphide (MnS) with sulphur, which is beneficial to machining. At the same time, it counters the brittleness from sulphur and is beneficial to the surface finish of carbon steel.

Manganese could be the second most important element after Carbon on steel. Mn has effects similar to those of carbon, and the steel producer uses these two elements in combination to obtain a material with the desired properties. Manganese is a necessity for the process of hot rolling of steel by its combination with oxygen and sulfur.

- Its presence has below main effects:
- It is a mild de-oxidant acting as a cleanser taking the sulphur and oxygen out of the melt into the slag.
- It increases the harden ability and tensile strength but decreases ductility.
- It combines with sulphur to form globular manganese sulphides, essential in free cutting steels for good machinability.
- Steels usually contain at least 0.30% manganese, however, amounts of up to 1.5% can be found in some carbon steels.
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EFFECT OF PHOSPHORUS $^{15}P_{30.973761}$

- Phosphorus increases strength and hardness, but at the expense of ductility and impact to toughness, especially in higher carbon steels that are quenched and tempered. As such its content in most steel is limited to a maximum of 0.05%. Phosphorus prevents the sticking of light-gage sheets when it is used as an alloy in steel. It strengthens low carbon steel to a degree, increases resistance to corrosion and improves machinability in free-cutting steels. In terms of welding, phosphorus content of over 0.04% makes weld brittle and increases the tendency to crack. The surface tension of the molten weld metal is lowered, making it difficult to control.
- Although it increases the tensile strength of steel and improves machinability it is generally regarded as an undesirable impurity because of its embrittling effect.
- Effect of phosphorus element will have various effects on steel depending on concentration.

- The maximum amount of phosphorus in higher grade steel is between 0.03 to 0.05% due to the fact that is detrimental. Up to 0.10% of phosphorus in low-alloy high-strength steels will increase the strength as well as improve the steel's resistance against corrosion. The possibility of brittlement increases when the content in hardened steel is too high. Even though the strength and hardness is improved, the ductility and toughness decreases.
- The machinability is improved in free-cutting steel, but weld brittle and/or weld cracks can occur during welding if the phosphorus content is more than 0.04%. Phosphorus also affects the thickness of the zinc layer when galvanising steel.

EFFECT OF SILICON $^{14}Si_{28.0855}$

- Silicon increases strength and hardness but to a lesser extent than manganese. It is one of the principal deoxidizers used in the making of steels to improve soundness, i.e. to be free from defects, decays or damages. Silicon is present in all steels to a certain extent. Its content can be up to 4% for electric sheets that are widely used in alternating current magnetic circuits.

- In welding, silicon is detrimental to surface quality, especially in the low carbon, resulphurized grades. It aggravates cracking tendencies when the carbon content is fairly high. For best welding condition, silicon content should not exceed 0.10%. However, amounts up to 0.30% are not as serious as high sulphur or phosphorus content.

- For galvanizing purposes, steels containing more than 0.04% silicon can greatly affect the thickness and appearance of the galvanized coating. This will result in thick coatings consisting mainly zinc-iron alloys and the surface has a dark and dull finish. But it provides as much corrosion protection as a shiny galvanized coating where the outer layer is pure zinc.
- Silicon is one of the principal deoxidizers for steel. Silicon helps to remove bubbles of oxygen from the molten steel. It is the element that is most commonly used to produce semi- and fully killed steels, and normally appears in amounts less than 0.40 percent, usually only small amounts (0.20%) are present in rolled steel when it is used as a deoxidizer. However, in steel castings, 0.35 to 1.00% is commonly present.

- Silicon dissolves in iron and tends to strengthen it. Some filler metals may contain up to 1% to provide enhanced cleaning and deoxidation for welding on contaminated surfaces. When these filler metals are used for welding on clean surfaces, the resulting weld metal strength will be markedly increased. Silicon increases strength and hardness but to a lesser extent than manganese. The resulting decrease in ductility could resent cracking problems.

CHROMIUM (CR)

- Chromium is a powerful alloying element in steel. Cr presents in certain structural steels in small amounts. It is primarily used to increase hardenability of steel and increase the corrosion resistance as well as the yield strength of the steel material. For that reason often occurs in combination with nickel and copper. Stainless steels may contain in excess of 12% chromium. The well-known “18-8” stainless steel contains 8 percent of nickel and 18 percent of chromium.
- When the percent of chromium in the steel exceeds 1.1% a surface layer is formed that helps protect the steel against oxidation.

TUNGSTEN (W)

- It is used with chromium, vanadium, molybdenum, or manganese to produce high speed steel used in cutting tools. Tungsten steel is said to be "red-hard" or hard enough to cut after it becomes red-hot. After heat treatment the steel maintains its hardness at high temperature making it particularly suitable for cutting tools.
- Tungsten in the form of tungsten carbide
- Gives steel high hardness even at red heats.
- Promotes fine grains
- Resists heat
- Promote strength at elevated temperatures

MOLYBDENUM (MO)

- Molybdenum has effects similar to manganese and vanadium, and is often used in combination with one or the other. This element is a strong carbide former and is usually present in alloy steels in amounts less than 1%. It increases hardenability and elevated temperature strength and also improves corrosion resistance as well as increased creep strength. It is added to stainless steels to increase their resistance to corrosion and is also used in high speed tool steels.

COBALT (CO)

- Cobalt improves strength at high temperatures and magnetic permeability.
- Increases hardness, also allows for higher quenching temperatures (during the heat treatment procedure). Intensifies the individual effects of other elements in more complex steels. Co is not a carbide former, however adding Cobalt to the alloy allows for higher attainable hardness and higher red hot hardness.

NICKEL (NI)

- In addition to its favorable effect on the corrosion resistance of steel, Ni is added to steels to increase hardenability. Nickel enhances the low-temperature behavior of the material by improving the fracture toughness. The weldability of the steel is not decreased by the presence of this element. The nickel drastically increases the notch toughness of the steel.
- Nickel is often used in combination with other alloying elements, especially chromium and molybdenum. It is a key component in stainless steels but at the low concentrations found in carbon steels. Stainless steels contain between 8% and 14% nickel.
- One more reason Ni is added to an alloy is that it creates brighter portions in damascus steels.

ALUMINUM (AL)

- Aluminum is one of the most important deoxidizers in very small amounts in the material, and also helps form a more fine-grained crystalline microstructure and increase the steel grade's toughness. It is usually used in combination with silicon to obtain a semi- or fully killed steel.

TITANIUM (TI)

- Ti is used to control grain size growth, which improves toughness. Also transforms sulfide inclusions form elongated to globular, improving strength and corrosion resistance as well as toughness and ductility.
- Ti is a very strong, very lightweight metal that can be used alone or alloyed with steels. It is added to steel to give them high strength at high temperatures. Modern jet engines used titanium steels.
- It prevents localized depletion of chromium in stainless steels during long heating
- Prevents formation of austenite in high chromium steels
- Reduces martensitic hardness and hardenability in medium chromium steels.