ALLOYING ELEMENTS IN STEEL

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Steel is essentially iron and carbon alloyed with certain additional elements.

The process of alloying is used to change the chemical composition of steel and improve its properties over carbon steel or adjust them to meet the requirements of a particular application.

Different alloying elements each have their own affect on the properties of steel. Some of the properties that can be improved through alloying include:

Stabilizing austenite: Elements such as nickel, manganese, cobalt and copper increase the temperatures range in which austenite exists.

Stabilizing ferrite: Chromium, tungsten, molybdenum, vanadium, aluminum and silicon can have the effect of lowering carbon's solubility in austenite. This results in an increase in the amount of carbides in the steel and decreases the temperature range in which austenite exists.

Carbide forming: Many minor metals, including chromium, tungsten, molybdenum, titanium, niobium, tantalum and zirconium, form strong carbides that - in steel - increase hardness and strength. Such steels are often used to make high speed steel and hot work tool steel.

Graphitizing: Silicon, nickel, cobalt and aluminum can decrease the stability of carbides in steel, promoting their breakdown and the formation of free graphite.

Decrease of eutectoid concentration: Titanium, molybdenum, tungsten, silicon, chromium and nickel all lower the eutectoid concentration of carbon.

Increase corrosion resistance: Aluminum, silicon and chromium form protective oxide layers on the surface of steel, thereby protecting the metal from further deterioration in certain environments.

Below is a list of commonly used alloying elements and their affect on steel (standard content in brackets):

Aluminum – Al (0.95-1.30%): A deoxidizer.   Al is used to limit growth of austenite grains.

Boron – B (0.001-0.003%): A hardenability agent that improves deformability and machinability. Boron is added to fully killed steel and only needs to be added in very small quantities to have a hardening affect. *Small amounts of Titanium + Aluminum help boron additions resist nitriding or oxidation to increase the yield from boron's hardenability effect.* Additions of boron are most effective in low carbon steels.

Chromium – Cr (0.5-18%): A key component of stainless steels. At over 12 percent content, chromium significantly improves corrosion resistance. The metal also improves hardenability, strength, response to heat treatment and wear resistance.

Cobalt – Co: Improves strength at high temperatures and magnetic permeability.

Copper – Cu (0.1-0.4%): Most often found as a residual agent in steels, copper is also added to produce precipitation hardening properties and increase corrosion resistance.

Lead – L: Although virtually insoluble in liquid or solid steel, lead is sometimes added to carbon steels via mechanical dispersion during pouring in order to improve machinability.

Manganese – Mn (0.25-13%): Increases strength at high temperatures by eliminating the formation of iron sulfides. Manganese also improves hardenability, ductility and wear resistance. Like nickel, manganese is an austenite forming element and can be used in the AISI 200 Series of Austenitic stainless steels as a substitute for nickel.

Molybdenum – Mo (0.2-5.0%): Found in small quantities in stainless steels, molybdenum increases hardenability and strength, particular at high temperatures. Often used in chromium-nickel austenitic steels, molybdenum protects against pitting corrosion caused by chlorides and sulfur chemicals.

Nickel – Ni (2-20%): Another alloying element critical to stainless steels, nickel is added at over 8% content to high chromium stainless steel. Nickel increases strength, impact strength and toughness, while also improving resistance to oxidization and corrosion. It also increases toughness at low temperatures when added in small amounts.

Niobium – Nb: Has the benefit of stabilizing carbon by forming hard carbides and, so, is often found in high temperature steels. In small amounts, niobium can significantly increase the yield strength and, to a lesser degree, the tensile strength of steels, as well as have a moderate precipitation strengthening affect.

Nitrogen – N: Increases the austenitic stability of stainless steels and improves yield strength in such steels.

Phosphorus – P: Phosphorus is often added with sulphur to improve machinability in low alloy steels. It also adds strength and increases corrosion resistance.

Selenium – Se: Increases machinability.

Silicon – Si (0.2-2.0%): This metalloid improves strength, elasticity, acid resistance and results in larger grain sizes, thereby, leading to greater magnetic permeability. Because silicon is used in a deoxidizing agent in the production of steel, it is almost always found in some percentage in all grades of steel.

Sulfur ("Sulphur" - British) – S (0.08-0.15%): Added in small amounts, sulphur improves machinability without resulting in hot shortness. With the addition of manganese hot shortness is further reduced due to the fact that manganese sulphide has a higher melting point than iron sulphide.

Titanium – Ti: Improves both strength and corrosion resistance while limiting austenite grain size. At 0.25-0.60 percent titanium content, carbon combines with the titanium, allowing chromium to remain at grain boundaries and resist oxidization. *Also used to maintain boron content additions in low carbon boron steels (10b35).*

Tungsten – W: Produces stable carbides and refines grain size so as to increase hardness, particularly at high temperatures. *Used to make high speed tool steels for drills + cutters that do not loose their hardness sharpness at high temperatures.*

Vanadium – V (0.15%): Like titanium and niobium, vanadium can produce stable carbides that increase strength at high temperatures. By promoting a fine grain structure, ductility can be retained.

Zirconium – Zr (0.1%): Increases strength and limits grains sizes. Strength can be notably increased at very low temperatures (below freezing). Steel's that include zirconium up to about 0.1% content will have smaller grains sizes and resist fracture.

Sources:

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