



Effects of Elements on Steel Properties

Steels are among the most commonly used alloys. The complexity of steel alloys is fairly significant. Not all effects of the varying elements are included. The following text gives an overview of some of the effects of various alloying elements. Additional research should be performed prior to making any design or engineering conclusions.

Carbon has a major effect on steel properties. Carbon is the primary hardening element in steel. Hardness and tensile strength increases as carbon content increases up to about 0.85% C as shown in the figure above. Ductility and weldability decrease with increasing carbon.

Manganese is generally beneficial to surface quality especially in re-sulfurised steels. Manganese contributes to strength and hardness, but less than carbon. The increase in strength is dependent upon the carbon content. Increasing the manganese content decreases ductility and weldability, but less than carbon. Manganese has a significant effect on the hardenability of steel.

Phosphorus increases strength and hardness and decreases ductility and notch impact toughness of steel. The adverse effects on ductility and toughness are greater in quenched and tempered higher-carbon steels. Phosphorous levels are normally controlled to low levels. Higher phosphorus is specified in low-carbon free-machining steels to improve machinability.

Sulphur decreases ductility and notch impact toughness especially in the transverse direction. Weldability decreases with increasing sulphur content. Sulphur is found primarily in the form of sulphide inclusions. Sulphur levels are normally controlled to low levels. The only exception is free-machining steels, where sulphur is added to improve machinability.

Silicon is one of the principal deoxidisers used in steelmaking. Silicon is less effective than manganese in increasing as-rolled strength and hardness. In low-carbon steels, silicon is generally detrimental to surface quality.

Copper in significant amounts is detrimental to hot-working steels. Copper negatively affects forge welding, but does not seriously affect arc or oxyacetylene welding. Copper can be detrimental to surface quality. Copper is beneficial to atmospheric corrosion resistance when present in amounts exceeding 0.20%. Weathering steels are sold having greater than 0.20% Copper.

Lead is virtually insoluble in liquid or solid steel. However, lead is sometimes added to carbon and alloy steels by means of mechanical dispersion during pouring to improve the machinability.



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Boron is added to fully killed steel to improve hardenability. Boron-treated steels are produced to a range of 0.0005 to 0.003%. Whenever boron is substituted in part for other alloys, it should be done only with hardenability in mind because the lowered alloy content may be harmful for some applications. Boron is a potent alloying element in steel. A very small amount of boron (about 0.001%) has a strong effect on hardenability. Boron steels are generally produced within a range of 0.0005 to 0.003%. Boron is most effective in lower carbon steels.

Chromium is commonly added to steel to increase corrosion resistance and oxidation resistance, to increase hardenability, or to improve high-temperature strength. As a hardening element, Chromium is frequently used with a toughening element such as nickel to produce superior mechanical properties. At higher temperatures, chromium contributes increased strength. Chromium is a strong carbide former. Complex chromium-iron carbides go into solution in austenite slowly; therefore, sufficient heating time must be allowed for prior to quenching.

Nickel is a ferrite strengthener. Nickel does not form carbides in steel. It remains in solution in ferrite, strengthening and toughening the ferrite phase. Nickel increases the hardenability and impact strength of steels.

Molybdenum increases the hardenability of steel. Molybdenum may produce secondary hardening during the tempering of quenched steels. It enhances the creep strength of low-alloy steels at elevated temperatures.

Aluminium is widely used as a deoxidiser. Aluminium can control austenite grain growth in reheated steels and is therefore added to control grain size. Aluminium is the most effective alloy in controlling grain growth prior to quenching. Titanium, zirconium, and vanadium are also valuable grain growth inhibitors, but their carbides are difficult to dissolve into solution in austenite.

Zirconium can be added to killed high-strength low-alloy steels to achieve improvements in inclusion characteristics. Zirconium causes sulphide inclusions to be globular rather than elongated thus improving toughness and ductility in transverse bending.

Niobium (Columbium) increases the yield strength and, to a lesser degree, the tensile strength of carbon steel. The addition of small amounts of Niobium can significantly increase the yield strength of steels. Niobium can also have a moderate precipitation strengthening effect. Its main contributions are to form precipitates above the transformation temperature, and to retard the recrystallisation of austenite, thus promoting a fine-grain microstructure having improved strength and toughness.

Titanium is used to retard grain growth particularly at high temperatures and thus improves toughness. Titanium is also used to achieve improvements in inclusion characteristics. Titanium causes sulphide inclusions to be globular rather than elongated thus improving toughness and ductility in transverse bending.



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Vanadium increases the yield strength and the tensile strength of carbon steel. The addition of small amounts of Niobium can significantly increase the strength of steels. Vanadium is one of the primary contributors to precipitation strengthening in microalloyed steels. When thermomechanical processing is properly controlled the ferrite grain size is refined and there is a corresponding increase in toughness. The impact transition temperature also increases when vanadium is added.

All microalloy steels contain small concentrations of one or more strong carbide and nitride forming elements. Vanadium, niobium, and titanium combine preferentially with carbon and/or nitrogen to form a fine dispersion of precipitated particles in the steel matrix