New Hampshire MATERIALS LABORATORY, INC.
Your Problem Solving Partner

Alloy Element Table

A substitution of an alloy element can change the composition of the alloyed steel causing unforeseen problems. NHML receives numerous calls a year requesting to have the alloying elements in steel verified for this reason.

We have provided below a table of alloying elements, their principle functions, and carbide tendencies. If you work with any of these materials and experienced problems, call to speak to one of our knowledgeable staff members. We may be able to help provide an answer.

Alloying Element	Carbide Forming Tendency	Principle Functions
Aluminum	Less than iron, promotes graphitization	• With nitrogen or oxygen, aluminum forms a fine dispersion that limits grain growth • A deoxidizer that results in excellent toughness because of the resulting fine grain size • Forms a surface hardened layer by (relatively) low temperature diffusion of nitrogen (nitriding)
Boron	Moderate	• Significantly increased harden ability in the 0.0005 to 0.003% range, without sacrificing ductility or machinability
Calcium	None	• When used as a deoxidizer, it provides better machinability than aluminum or silicon • Controls inclusion shape in HSLA steels, improving toughness
Carbon	None	• The most important alloying element in steel as it forms pearlite, bainite, spherodite, and iron-carbon martensite • Increasing carbon increases hardness, strength, and ductile-brittle transition temperature • Increasing carbon decreases toughness and ductility
Chromium	Greater than manganese and less than tungsten	• Provides a moderate contribution to hardenability up to about 1% • Mildly resists softening during tempering • Provides elevated temperature strength and resistance to oxidation • With high carbon, provides abrasion resistance
Cobalt	About the same as iron	• Resist softening at elevated temperatures

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Copper	None	• Improves resistance to atmospheric corrosion in the 0.20 – 0.50% range • Decreases the ability to hot work steels due to migration to grain boundaries
Lead	None	• Does not dissolve in steel and improves machinability • Can cause liquid metal embrittlement at temperatures near its melting point
Manganese	Greater than iron, less than chromium	• Provides a moderate contribution to hardenability up to about 2% • Promotes retained austenite on quenching • Forms sulfides for improved machinability • Produces a high carbon austenitic steel • Produces a Cr-Ni-Mn austenitic steel (200 series stainless) that competes with the 300 series stainless steels • Increases strength and reduces ductility in ferritic steels • Is a deoxidizer and promotes hot workability
Molybdenum	Strong carbide former, greater than chromium or tungsten	• Contributes greatly to hardenability up to about 1% • Contributes deep hardening • Increases elevated temperature strength and creep resistance • Improves corrosion resistance in stainless steels, particularly in chloride environments • Minimizes the tendency toward temper embrittlement in alloy steels in the 0.15 to 0.30% range
Nickel	Less than iron, promotes graphitization	• Provides a moderate contribution to hardenability • Tends to promote retained austenite with medium and high carbon contents • Strengthens unhardened steels by solid solution • Makes high chromium steels austenitic • Provides toughness in ferritic-pearlitic steels

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Niobium	Strong	• Produces fine grain size • Increases elevated temperature strength • As a strong carbide former it can decrease the hardenability of steel by removing carbon from solution
Phosphorus	None	• Provides a high contribution to hardenability • Promotes retained austenite • Strengthens carbon steels but severely reduces toughness and ductility • Improves corrosion resistance • Improves machinability is high sulfur steels • Decreases ductility with medium and high carbon steels • Contributes to temper embrittlement
Silicon	None, promotes graphitization	• Provides a moderate increase in hardenability • Hardens ferrite, more than manganese but less than phosphorus, up to about 1% • Increases the strength of quenches and tempered steels • Provides some oxidation resistance at elevated temperatures • Is a general purposes deoxidizer, at about 0.05% in rimmed steels and 0.15 – 0.30% in fully killed steels
Sulfur	None	• Normally present as manganese sulfide stringers sulfur • Decreases transvers strength and ductility but has little effect on longitudinal properties • Decreases weldability • Enhances machinability

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Titanium	Stronger than all other elements except niobium/columbium	• Produces carbide particles that restrict grain growth • Reduces martensite hardness by removing carbon from solution • Removes carbon from solution in austenitic stainless steels preventing grain boundary deterioration by chromium carbide formation • Inhibits austenite formation in high chromium steels • Acts as a deoxidizer by combining with oxygen and nitrogen
Tungsten	Stronger than molybdenum	• Decreases softening during tempering • Forms abrasion resistant carbides • Promotes elevated temperature hardness • Provides some creep resistance
Vanadium	Strong, but less than titanium or niobium	• Provides a significant increase in hardenability up to about 0.05% • Promotes fine austenite grain size • Resists softening during tempering

Hardenability Calculation:

A number of elements have been noted as having the ability to increase hardenability. Burns, Moore, and Archer (ASM Trans.1938) developed a chemical factor calculation to quantify the effect of alloying additions. The chemical factor, as computed below has a direct relationship with Rockwell-inch hardenability.

Chemical factor = 1000 (%C) + 500 (%Mn) + 400 (%Cr) + 100 (%Ni) + 25 (%Cu) + 1000 (%Mo)

Note that while no alloying additions result in sudden increases, or decreases in mechanical properties, corrosion resistance may be significantly altered by small changes in composition.