MetallurgyData

Effect of Alloy Elements on the Heat Treatment of Quenched and Tempered Steels.

Element	Effect on Hardenability	Effect on Tempering
Manganese	Mn contributes markedly to hardenability in amounts greater than 0.8%. The effect of Mn up to 1.0% is stronger in low and high carbon steels than in medium carbon steels.	Mn increases the hardness of tempered martensite by retarding the coalescence of carbides, which prevent grain growth in the ferrite matrix. These effects cause a substantial increase in the hardness of tempered martensite as the % Mn increases.
Nickel	Ni is similar to Mn at low alloy conditions, but is less potent at the high alloy levels. Ni is also affected by carbon content, the medium-carbon steels having the greatest effect, there is an alloy interaction between Mn and Ni must be taken into account at lower austenitising temperatures.	Ni has a relatively small effect on the hardness of tempered martensite, which is essentially the same at all tempering temperatures. Because Ni is not a carbide former, its influence is considered to be due to a weak solid-solution strengthening.
Copper	Cu is usually added to alloy steels for its contribution to atmospheric corrosion resistance and at higher levels (>1.0%) for precipitation hardening. The effect of Cu on hardenability is similar to that of Ni, and in hardenability calculations it has been suggested that the sum of Cu+Ni be used with the appropriate multiplying factor for Ni.	Cu is precipitated out when the steel is heated to about 425-650°C and can provide a degree of precipitation strengthening, normally in steels containing >1.0% Cu.
Silicon	Si is more effective than Mn at low alloy levels and has a strengthening effect on low alloy steels. However at levels >1% this element is much less effective than Mn. The effect of Si also varies considerably with carbon content and other alloys present. Si is ineffective in low-carbon steels but is effective in high carbon steels.	Si increases the hardness of tempered martensite at all tempering temperatures. Si also has a substantial retarding effect on softening at 316°C, and has been attributed to the inhibiting effect of Si on the conversion of E carbide to cementite.
Molybdenum	Mo is most effective in improving hardenability. Mo has a much greater effect in high carbon steels than in medium carbon steels. The	Mo retards the softening of martensite at all tempering temperatures. Above 540°C Mo partitions to the carbide phase and

MetallurgyData

	presence of Cr decreases the multiplying factor, whereas the presence of Ni enhances the hardenability effect of Mo.	thus keeps the carbide particles small and numerous. In addition, Mo reduces the susceptibly to temper embrittlement.
Chromium	Cr behaves much like Mo and has its greatest effect in medium carbon steels. In low carbon steels and carburised steels, the effect is less than in medium carbon steels, but is still significant. As a result of the stability of CrC at low austenitising temperatures, the effect of Cr becomes less effective.	Cr, like Mo, is a strong carbide forming element that can be expected to retard the softening of martensite at all temperatures. Also, by substitution of chromium for some of the iron in cementite, the coalescence of carbides is retarded.
Vanadium	V is not added for hardenability in QT steels, but is added to provide secondary hardening during tempering. V is a strong carbide former and the steel must be austenitised at a sufficiently high temperature and for a sufficient time to ensure that the V is in solution.	V is a stronger carbide forming element than Mo or Cr and can be expected to have a more powerful effect at equivalent alloy level. The strong effect of V is due to the formation of an alloy carbide that replaces cementite type carbides at high temperatures and remains as a fine dispersion up to the Ar temperature.
Titanium, Niobium	Both are strong carbide formers and are not usually added for hardenability.	These elements should act in similar manner to that of V because they are also strong carbide formers.
Boron	B can considerably improve the hardenability, the effect varying with the carbon content of the steel. The full hardening of B is contained when the steel is fully deoxidised.	B has no effect on the tempering characteristics of martensite, but a detrimental effect on toughness can result from the transformation to non-martensitic products.