Characteristic of alloying elements

**Sumário:**
Very important elements for alloy steels are manganese, nickel, chromium, molybdenum, vanadium, tungsten, silicon, copper, cobalt and boron. All commercial steels contain 0.3-0.8% manganese, to reduce oxides and to counteract the harmful influence of iron sulphide. There is a tendency nowadays to increase the manganese content and reduce the carbon content in order to get a steel with an equal tensile strength but improved ductility. Nickel and manganese are very similar in behaviour and both lower the eutectoid temperature. Nickel steels are noted for their strength, ductility and toughness, while chromium steels are characterized by their hardness and resistance to wear. Chromium can dissolve in either alpha- or gamma-iron, but, in the presence of carbon, the carbides formed are cementite (Fe₃C) in which chromium may rise to more than 15%; chromium carbides (Cr₆C₃, Cr₃C₂, Cr₇C₃), in which chromium may be replaced by a few per cent, by a maximum of 55% and by 25% respectively. The chrome steels are used wherever extreme hardness is required, such as in dies, ball bearings, plates for safes, rollers, files and tools. The combination of nickel and chromium produces steels having all these properties, some intensified, without the disadvantages associated with the simple alloys. Molybdenum dissolves in both alpha- or gamma-iron and in the presence of carbon forms complex carbides (FeMo₆C, Fe₂₃Mo₂C₆, Mo₇C₃). Molybdenum is also a constituent in some high-speed steels, magnet alloys, heat-resisting and corrosion-resisting steels.

**Manganese**
All commercial steels contain 0.3-0.8% manganese, to reduce oxides and to counteract the harmful influence of iron sulphide. Any manganese in excess of these requirements partially dissolves in the iron and partly form Mn₃C which occurs with the Fe₃C. There is a tendency nowadays to increase the manganese content and reduce the carbon content in order to get a steel with an equal tensile strength but improved ductility.

If the manganese is increased above 1.8%, the steel tends to become airhardened, with resultant impairing of the ductility. Up to this quantity, manganese has a beneficial effect on the mechanical properties of oil hardened and tempered 0.4% carbon steel. The manganese content is also increased in certain alloy steels, with a reduction or elimination of expensive nickel. In order to reduce costs. Steels with 0.3-0.4% carbon, 1.3-1.6% manganese and 0.3% molybdenum have replaced 3% nickel steels for some purposes.

Non-shrinking tool steel contains up to 2% manganese, with 0.8-0.9% carbon. Steels with 5 to 12% manganese are martensitic after slow cooling and have little commercial importance. Hadfield’s manganese steel contains 12 to 14% of manganese and 1.0% of carbon. It is characterized by a great resistance to wear and is therefore used for railway points, rock drills and stonemushers. Austenite is completely retained by quenching the steel from 1000°C, in which soft condition it is used, but abrasion raises the hardness of the surface layer from 200 to 600 VPN (with no magnetic change), while the underlying material remains rough. Annealing embrittles the steel by the formation of carbides at the grain boundaries. Nickel is added to electrodes for welding manganese steel and 2% Mo sometimes added, with a prior carbide dispersion treatment at 600°C, to minimize initial distortion and spreading.

**Nickel**
Nickel and manganese are very similar in behavior and both lower the eutectoid temperature. This change point on heating is lowered progressively with increase of nickel (approximately 10°C for 1% of nickel), but the lowering of the change on cooling is greater and irregular. The temperature of this change (Ar₁) is plotted for different nickel contents for 0.2% carbon steels in Fig. 1, and it will be seen that the curve takes a sudden plunge round about 8% nickel. A steel with 12% nickel begins to transform below 300°C on cooling, but on reheating the reverse change does not occur until about 650°C. Such steels are said to exhibit pronounced hysteresis and are called irreversible steels. This characteristic is made use of in maraging steels and 9% Ni cryogenic steel.

The addition of nickel acts similarly to increasing the rate of cooling of a carbon steel. Thus with a constant rate of cooling the 5-8% nickel steels become troostitic; at 8-10% nickel, where the sudden drop appears, the structure is martensitic, while above 24% nickel the critical point is depressed below room temperature and austenite remains. The lines of demarcation are not so sharp as indicated by Fig. 1, but a gradual transition occurs from one constituent to another.
The mechanical properties change accordingly as shown in the lower part of Fig. 1. Steels with 0.5% nickel are similar to carbon steel, but are stronger, on account of the finer pearlite formed and the presence of nickel in solution in the ferrite. When 10% nickel is exceeded the steels have a high tensile strength, great hardness, but are brittle, as shown by the Izod and elongation curves. When the nickel is sufficient to produce austenite the steels become non-magnetic, ductile, tough and workable, with a drop in strength and elastic limit. Carbon intensifies the action of nickel and the change points shown in Fig. 1 will vary according to the carbon content. The influence of carbon and nickel on the structure are shown in the small inset (Guillet) diagram in Fig. 1, for one rate of cooling. Steels containing 2 to 5% nickel and about 0.1% carbon are used for case hardening; those containing 0.25 to 0.40% carbon are used for crankshafts, axles and connecting rods.

The superior properties of low nickel steels are best brought out by quenching and tempering (550-650°C). Since the Ac₃ point is lowered, a lower hardening temperature than for carbon steels is permissible and also a wider range of hardening temperatures above Ac₃ without excessive grain growth, which is hindered by the slow rate of diffusion of the nickel. Martensitic nickel steels are not utilized and the austenitic alloys cannot compete with similar manganese steels owing to the higher cost. Maraging steels have fulfilled a high tensile requirement in aero and space fields. High nickel alloys are used for special purposes, owing to the marked influence of nickel on the coefficient of expansion of the metal. With 36% nickel, 0.2% carbon, 0.5% manganese, the coefficient is practically zero between 0° and 100°C. This alloy ages with time, but this can be minimized by heating at 100°C for several days. The alloy is called Invar and it is used extensively in clocks, tapes and wire measures, differential expansion regulators, and in aluminium pistons with a split skirt in order to give an expansion approximating to that of cast iron.

A carbon-free alloy containing 78.5% nickel and 21.5% iron has a high permeability in small magnetic fields.

Chromium

Chromium can dissolve in either alpha- or gama-iron, but, in the presence of carbon, the carbides formed are cementite (Fe₃Cr) in which chromium may rise to more than 15%; chromium carbides (CrFe)₃C, (CrFe)₇C₃, (CrFe)₄C, in which chromium may be replaced by a few per cent, by a maximum of 55% and by 25% respectively. Stainless steels contain Cr₄C.

The pearlitic chromium steels with, say, 2% chromium are extremely sensitive to rate of cooling and temperature of heating before quenching; for example:

<table>
<thead>
<tr>
<th>Temp. of Initial Heating, °C</th>
<th>Critical Hardening Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Mins to cool from 836° to 546°C)</td>
</tr>
<tr>
<td>836</td>
<td>3.5</td>
</tr>
<tr>
<td>1010</td>
<td>6.5</td>
</tr>
<tr>
<td>1200</td>
<td>13</td>
</tr>
</tbody>
</table>

The reason is that the chromium carbides are not readily dissolved in the austenite, but the amount increases with increase of temperature. The effect of the dissolved chromium is to raise the critical points on heating (AC) and also on cooling (Ar) when the rate is slow. Faster rates of cooling quickly depress the Ar points with consequent hardening of the steel. The pearlite is rendered fine.

When the chromium exceeds 1.1% in low-carbon steels an inert passive film is formed on the surface which resists attack by oxidizing reagents. Still higher chromium contents are found in...