

in varying percentages; they can also contain copper and boron as specified additions. To qualify as a *carbon steel*, a steel's maximum concentrations of manganese, silicon, and copper must not exceed 1.65%, .60%, and .60%, respectively. With the exception of boron and deoxidizers, no other alloy element is intentionally added. *Alloy steels* comprise those steel grades that exceed the above limits, as well as any grade to which an element other than those previously mentioned is added to achieve a specific alloy effect.

The effects of the following chemical elements on the properties of hot-rolled carbon and alloy bars are considered individually. In practice, the effect of a particular element often depends on the presence and quantities of other elements in the steel. For example, the total effect of a combination of elements on the hardness of a steel is usually greater than the sum of their individual effects. This interrelation should be considered when a change in a specified analysis is being evaluated. (With the exception of sulfur and phosphorous, Table 12 details the chemical composition of pharmaceutical tool steels.)

Carbon

Carbon is the principal hardening element in steel; each additional increment of carbon increases the hardness and tensile strength of steel in the as-rolled, or normalized, condition. As carbon content exceeds approximately .85%, the resultant increase in strength and hardness is proportionately less for each increment added. Upon quenching, the maximum attainable hardness also increases with increasing carbon; however, the

TABLE 12. CHEMICAL COMPOSITION OF TOOL STEELS

CHEMICAL ELEMENT	PERCENTAGE OF CHEMICAL ELEMENTS								
	408	S1	S5	S7	A2	D2	D3	440C	O1
CARBON	.50	.40– .55	.50– .65	.45– .55	.95– 1.05	1.40– 1.60	2.00– 2.35	.95– 1.20	.90
MANGANESE	.50	.10– .40	.60– 1.00	.20– .80	.00– 1.00	.00– .60	.00– .60	.00– 1.00	1.20
SILICON	.25	.15– 1.20	1.75– 2.25	.20– 1.00	.00– .50	.00– .60	.00– .60	.00– 1.00	.40
CHROMIUM	.75	1.00– 1.80	.00– .35	3.00– 3.50	4.75– 5.50	11.0– 13.0	11.0– 13.5	16.0– 18.0	.50
VANADIUM		.15– .30	.00– .35	.00– .35	.15– .50	.00– 1.10	.00– 1.00		.20
TUNGSTEN		1.50– 3.00					.00– 1.00		.20
MOLYBDENUM		.00– .50	.20– 1.35	1.30– 1.80	.90– 1.40	.70– 1.20		.00– .75	
NICKEL	3.00							.00– .50	
COBALT						.00– 1.00			

rate of increase is very small for carbon contents above .60%.

Conversely, a steel's ductility and weldability decrease as its carbon content increases. Ductility is the ease with which metal flows during compression. Carbon also has a moderate tendency to segregate within the ingot. Because carbon has a significant effect on steel properties, its segregation is frequently more important than the segregation of other elements in the steel.

Manganese

Manganese, which is present in all commercial steels, contributes significantly—but to a lesser degree than does carbon—to a steel's strength and hardness. The effectiveness of manganese depends largely on and is directly proportional to a steel's carbon content.

Manganese has a greater ability than any of the commonly used alloy elements to decrease the critical cooling rate during hardening, thereby increasing a steel's